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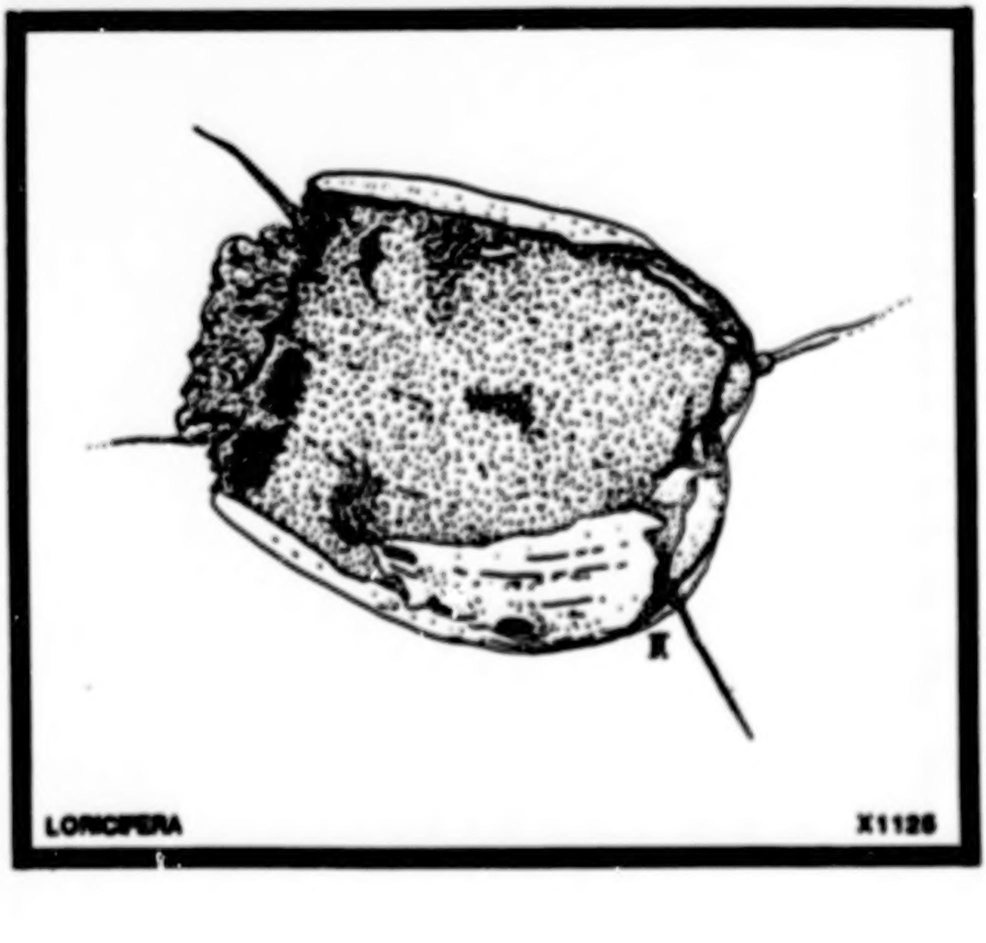
OCS Study
MMS 87-0059

Northern Gulf of Mexico Continental Slope Study Annual Report Year 3

Volume I: Executive Summary



U.S. Department of the Interior
MMS Minerals Management Service
Gulf of Mexico OCS Regional Office

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COVER:

In 1983, Reinhardt Kristensen of the University of Copenhagen, Denmark described a new phylum of animals, Loricifera, based upon specimens collected in 25 to 30-m depths near Roscoff, France; from 480-m deep waters near the Azores and from 15-m depths off Fort Pierce, Florida. This new phylum depicted on the cover was found to be well represented (506 specimens) across the entire continental slope of the northern Gulf of Mexico, from Florida to Texas, at depths from 298 to 2959 m.

OCS Study
MMS 87-0059

Northern Gulf of Mexico Continental Slope Study Annual Report Year 3

Volume I: Executive Summary

Contributing Editors

Benny J. Gallaway
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Prepared under MMS Contract 14-12-0001-30212

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Several persons contributed substantially to the writing of this report, although we must emphasize that this project was truly a team effort with much interaction and discussion of ideas, results and implications of the findings. However, below we recognize (alphabetically) those who "put words on paper".

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TABLE OF CONTENTS

Page

1.0 INTRODUCTION 3

1.1 PROGRAM OBJECTIVES AND CONTENT OF THIS REPORT 3
1.2 PROGRAM DESIGN AND INTEGRATION 5

1.2.1 PROGRAM SAMPLING DESIGN 5
1.2.2 FINAL REPORT PLAN 14

1.3 GUIDE TO AND NATURE OF THIS REPORT 18

2.0 STUDY AREA AND METHODS 23

2.1 STUDY AREA 23
2.2 CRUISES 26
2.3 METHODS 28

2.3.1 FIELD METHODS 28
2.3.2 LABORATORY METHODS 35
2.3.3 DATA MANAGEMENT 45

3.0 PHYSICAL AND CHEMICAL RESULTS 49

3.1 HYDROGRAPHY 49

3.1.1 TEMPERATURE 49
3.1.2 SALINITY 49
3.1.3 DISSOLVED OXYGEN 52
3.1.4 NUTRIENTS 54
3.1.5 PARTICULATE ORGANIC CARBON 58
3.1.6 DISSOLVED ORGANIC CARBON 58

3.2 SEDIMENTS 58

3.2.1 SEDIMENT CLASSIFICATION 58
3.2.2 SEDIMENT HYDROCARBONS 61

3.3 CARBON ISOTOPES 78

3.3.1 SEDIMENTS 78
3.3.2 ORGANISMS 81

3.4 ORGANISM HYDROCARBONS 82

4.0 BIOLOGICAL OCEANOGRAPHY OF THE NORTHERN GULF OF MEXICO CONTINENTAL SLOPE 89

4.1 MEIOFAUNA 93
4.2 MACROFAUNA 97

4.2.1 INTRODUCTION 97
4.2.2 COMMUNITY STRUCTURE 98
4.2.3 MACROFAUNA ABUNDANCE PATTERNS 98

Page

4.2.4 MACROFAUNA DIVERSITY PATTERNS 102
4.2.5 MAJOR GROUP ACCOUNTS 107

4.3 MEGAFAUNA 115

4.3.1 INTRODUCTION 115
4.3.2 COMMUNITY STRUCTURE AND DIVERSITY 115
4.3.3 MAJOR INVERTEBRATE GROUP DESCRIPTIONS 138

5.0 BENTHIC PHOTOGRAPHY RESULTS 145

6.0 REFERENCES 153

LIST OF FIGURES

Figure Page

1 Analysis design diagram for region, season and year comparisons 6

2 Two contrasting views of expected faunal changes that might be observed on the continental slope of the northern Gulf of Mexico 8

3 Analysis design diagram for zonation studies using density as the example response variable 9

4 Analysis design diagram for samples taken in the Eastern Gulf in spring 1985 to examine latitudinal versus depth variation 11

5 Analysis design diagram for samples taken between the Central and Western transects in summer 1985 to examine longitudinal versus depth variation 13

6 Stations sampled on each cruise 24

7 Box core and configuration of in situ subsampling tubes in the box corer 31

8 Schematic diagram of photographic system used for benthic photography 34

9 Sediment hydrocarbons analytical scheme 40

10 Hydrocarbon analysis scheme for organisms 41

11 Schematic representation of digitizing apparatus used for processing benthic photographs 44

12 Data flow sequence for Continental Slope Study 46

13 Hydrographic profiles, all cruises combined 50

14 Variation in temperature at selected depths measured at three stations across the Gulf during Cruise II 51

15 Variation in salinity at selected depths measured at three stations across the Gulf during Cruise II 53

16 Variation in dissolved oxygen at selected depths measured at three stations across the Gulf during Cruise II 55

17 Variation in nitrate at selected depths measured at three stations across the Gulf during Cruise II 56

18 Variation in phosphate at selected depths measured at three stations across the Gulf during Cruise II 57

19 Variation in particulate organic carbon at selected depths measured at three stations across the Gulf during Cruise II 59

20 Sediment map 60

Figure Page

21 Molecular level alkane distributions for sediments from the central transect during Cruise I 63

22 Variation in extractable organic matter and the aliphatic unresolved complex mixture along transects in the eastern, western, and central Gulf of Mexico continental slope 66

23 Variation in hydrocarbon source parameters along transects in the eastern, western, and central Gulf of Mexico continental slope 67

24 Variation in planktonic, terrestrial, and petroleum hydrocarbons along three transects presented as a cumulative concentration 68

25 The relationship between alkane petroleum indicators and a terrestrial indicator 70

26 The relationship between the aliphatic unresolved complex mixture and the planktonic and terrestrial alkane indicator 71

27 Variations in extractable organic matter and the aliphatic unresolved complex mixture during three samplings of the central transect 73

28 Variations in hydrocarbon source parameters during three samplings of the central transect 74

29 Variation in plankton, terrestrial and petroleum hydrocarbons during three samplings of the central transect presented as a cumulative concentration 75

30 Variation in the carbon preference index as a function of depth along the Central Transect during Cruise III and a representative fused silica gas chromatogram of the aliphatic hydrocarbons from Station C5, Cruise III 76

31 Summary of the carbon isotopic composition of sedimentary organic matter from all five cruises 80

32 Summary of the carbon isotopic composition of organism tissues by organism type 83

33 Summary of the carbon isotopic composition of organism tissues by transect and organism type for all five cruises 84

34 Summary of the total alkane concentration in organism tissues for Cruises I, II and III 85

35 Relative occurrence of meiofauna and macrofauna with depth at all sampling stations 94

36 Plot of number of macrofaunal species versus number of individuals showing the great number of species that were collected few times compared to the fewer species that occurred in large numbers 100

37 Comparative levels of macrofaunal densities by region, season, year and selected depth interval 103

38 Comparative levels of macrofaunal density by depth on the Central Transect, Fall 1984 104

39 Comparative levels of macrofaunal density along selected isobaths in the Eastern Gulf of Mexico during Spring 1985 105

Figure Page

40 Comparative levels of macrofaunal density along isobaths between the Central and Western Gulf of Mexico sampling transects, Summer 1985 106

41 Comparative levels of macrofaunal diversity by region, season, year and selected depth interval 108

42 Comparative levels of macrofaunal diversity by depth on the Central Transect, Fall 1984 109

43 Comparative levels of macrofaunal diversity along selected isobaths in the Eastern Gulf of Mexico during Spring 1985 110

44 Comparative levels of macrofaunal diversity along isobaths between the Central and Western Gulf of Mexico sampling transects, Summer 1985 111

45 Species diversity and number of species of megafauna invertebrates for the Eastern Transect, Cruises I-V 118

46 Species diversity and number of species of megafauna invertebrates for the Central Transect, Cruises I-V 119

47 Species diversity and number of species of magafauna invertebrates for the Western Transect, Cruises I-V 120

48 Species diversity and number of species of fishes for the Eastern Transect, Cruises I-V 121

49 Species diversity and number of species of fishes for the Central Transect, Cruises I-V 122

50 Species diversity and number of species of fishes for the Western Transect, Cruises I-V 123

51 The range of depth covered by trawling isobathymetrically as nearly as possible along three "horizontal transects" of increasing depth in the Eastern sampling area 126

52 The range of depth covered at individual stations by trawling isobathymetrically as nearly as possible along three "horizontal transects" of increasing depth in the West-Central sampling area 127

53 All invertebrates taken by trawl from the 15 stations of Cruise IV on the Eastern Transect clustered by NESS at 30 individuals 128

54 All fishes taken by trawl from the 15 stations of Cruise IV on the Eastern Transect clustered by NESS at 30 individuals 129

55 All invertebrates taken by trawl from the 12 stations of Cruise V clustered by NESS at 30 individuals 131

56 All fishes taken by trawl from the 12 stations of Cruise V clustered by NESS at 30 individuals 132

57 All invertebrates from Cruises III (Central Transect), IV (East Transect), and V (West-Central Transect) 133

Figure Page

58 Species recruitment curve for fish species taken at all stations on the Central Transect 135

59 Chi-squared values for fish species taken on the Central Transect 135

60 Species recruitment curve for fish species trawled on the Western Transect 136

61 Chi-squared values for fish species taken on the Western Transect 136

62 Species recruitment curve for fish species trawled on the Eastern Transect 137

63 Chi-squared values for fish species taken on the Eastern Transect 137

64 Species recruitment curve for invertebrate species trawled from the Central Transect 139

65 Chi-squared values for invertebrate species trawled from the Central Transect 139

66 Species recruitment curve for all invertebrates trawled on the Western Transect 140

67 Chi-squared analysis of invertebrate species trawled on the Western Transect 140

68 Species recruitment curve for all invertebrates trawled on the Eastern Transect 141

69 Chi-squared analysis of invertebrate species trawled on the Eastern Transect 141

70 Total lebensspuren densities for Cruises II and III 146

71 Total biota density from benthic photography by Station, Cruises II-V 147

72 Megafauna density comparisons of trawl and benthic photography, Cruise III 149

73 Distribution by depth and length frequency distribution of *Peniagone* sp., Cruises II and III 150

LIST OF TABLES

Table — Page

1 Suggested molecular-level indicators of specific hydrocarbon sources to sediments on the Gulf of Mexico continental slope 62

2 Variability in hydrocarbon parameters along isobaths - eastern Gulf of Mexico 77

3 Variability in hydrocarbon parameters along isobaths - west/central Gulf of Mexico 79

4 Relative abundance of major macrofaunal groups 99

5 Rank order of dominant macrofaunal species 101

6 Densities of megafaunal invertebrates and demersal and benthopelagic fishes at six depth intervals on three major transects 117

1.0 INTRODUCTION

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1.0 INTRODUCTION

Since 1983, LGL Ecological Research Associates, Inc. (LGL) in conjunction with Texas A&M University (TAMU) has been conducting a study of the continental slope of the northern Gulf of Mexico for the Gulf of Mexico Regional Office of the Minerals Management Service (MMS). The overall objective of the program is to develop a basic knowledge of the deep Gulf fauna, their environment, and ecological processes in advance of extensive petroleum development.

Prior to initiation of this study, MMS had funded TerEco Corporation Inc. to synthesize all available environmental information for the Gulf slope. The resulting report (Pequegnat 1983) described and interpreted information through 1982, and, in large part, served as the basis for formulating the objectives of the present program. The Pequegnat (1983) document thus provided the background or baseline data against which the information gathered by this study can be compared and evaluated.

1.1 PROGRAM OBJECTIVES AND CONTENT OF THIS REPORT

The specific objectives of the Gulf of Mexico Continental Slope Study are:

(1) To determine the abundance, structure, and distribution of animal communities in the deep-sea in the Gulf of Mexico.

(2) To determine the hydrographic structure of the water column and bottom conditions at selected sites within the study area.

(3) To determine and compare sedimentary characteristics at selected sites within the study area.

(4) To relate differences in biological communities to hydrographic, sedimentary, and geographic variables.

(5) To assess seasonal changes in deep-sea biological communities in terms of abundance, structure, animal size, and reproductive state.

(6) To measure present levels of hydrocarbon contamination in the deep-sea sediments and selected animals prior to, and

in anticipation of, petroleum resource development beyond the shelf-slope break.

(7) To assemble together and synthesize appropriate published and unpublished data with the results of this study, summarizing on a seasonal and spatial basis all biological, habitat, and environmental observations and parameters.

(8) To compare the biological and non-biological characteristics of the deep Gulf of Mexico with that of other temperate and subtropical deep-sea regions.

(9) To assess the need for, and determine the type of studies to be conducted in future program efforts.

Two additional objectives were mainly met during the first two years of the program:

(10) To conduct an effective quality assurance and quality control program which insures that all data acquired are accurate and repeatable within standards normally required for each type of observation, measurement, or determination.

(11) To critically review, interpret, and analyze all observations and data acquired to redefine as necessary the research program in such a way as to avoid or minimize redundancy and to optimize the efficiency of all field, laboratory, and data management operations for future deep-sea studies sponsored by MMS in the Gulf of Mexico.

Activities during Years 1 and 2 were dedicated to field sampling and laboratory sample analyses. Year 3 has been dedicated to finishing the sample analyses, and compiling the data in usable and interactive format.

The acquisition of data for meeting the stated objectives occurred over the course of five cruises, all conducted during the first two years of the program. Because of the small size and taxonomic complexity of the macrofauna, all of contract Years 1-3 (1983-1986), as well as a time extension into 1987, were required to complete sample analysis. This report represents the first time that all data have been available for analysis.

The primary goals of the Year 3 Annual Report were to (1) provide a detailed description of all the field collection, laboratory analyses and data management methods that have been used (this volume), and (2) provide a comprehensive summary, in hard copy, of all the data that were collected and that have been submitted to NODC in specified tape report (Volume III Appendices). In the Year 4 Final Report, emphasis will be placed upon statistical analyses, interpretation and reporting of the findings, and only summary descriptions of the methods, and data detailed herein will be included in that report, mainly by reference.

In this report we present results of some initial exploratory analyses, we purposefully provide little in the way of interpretative comment. The Year 3 Annual Report has, as an analogy, the results section of a standard scientific paper. Following the same analogy, discussion of the results in terms of program objectives will be the focus of the Final Report for Year 4.

1.2 PROGRAM DESIGN AND INTEGRATION

As discussed above, this report is a descriptive treatise, that may appear to the reader to be a curious collection of disjointed results. The purpose of this section is to clarify how the results will be integrated for the Final Report planned for Year 4.

1.2.1 PROGRAM SAMPLING DESIGN

The program sampling plan was structured to first (based upon sampling conducted on Cruises I, II, III (in part) and IV (in part) compare environmental and biological attributes of the slope, by depth, among planning regions (Eastern, Central and Western Gulf, for site maps see Panels A, B and C of Fig. 7, Section 2) between seasons (fall versus spring), and between years (1983-84, 1984-85) by season (fall, spring, respectively) (Fig. 1). The depth selections were not random or evenly spaced down the slope but were rather the approximate mid-points of previously-defined (Pequegnat 1983) biological depth assemblages or

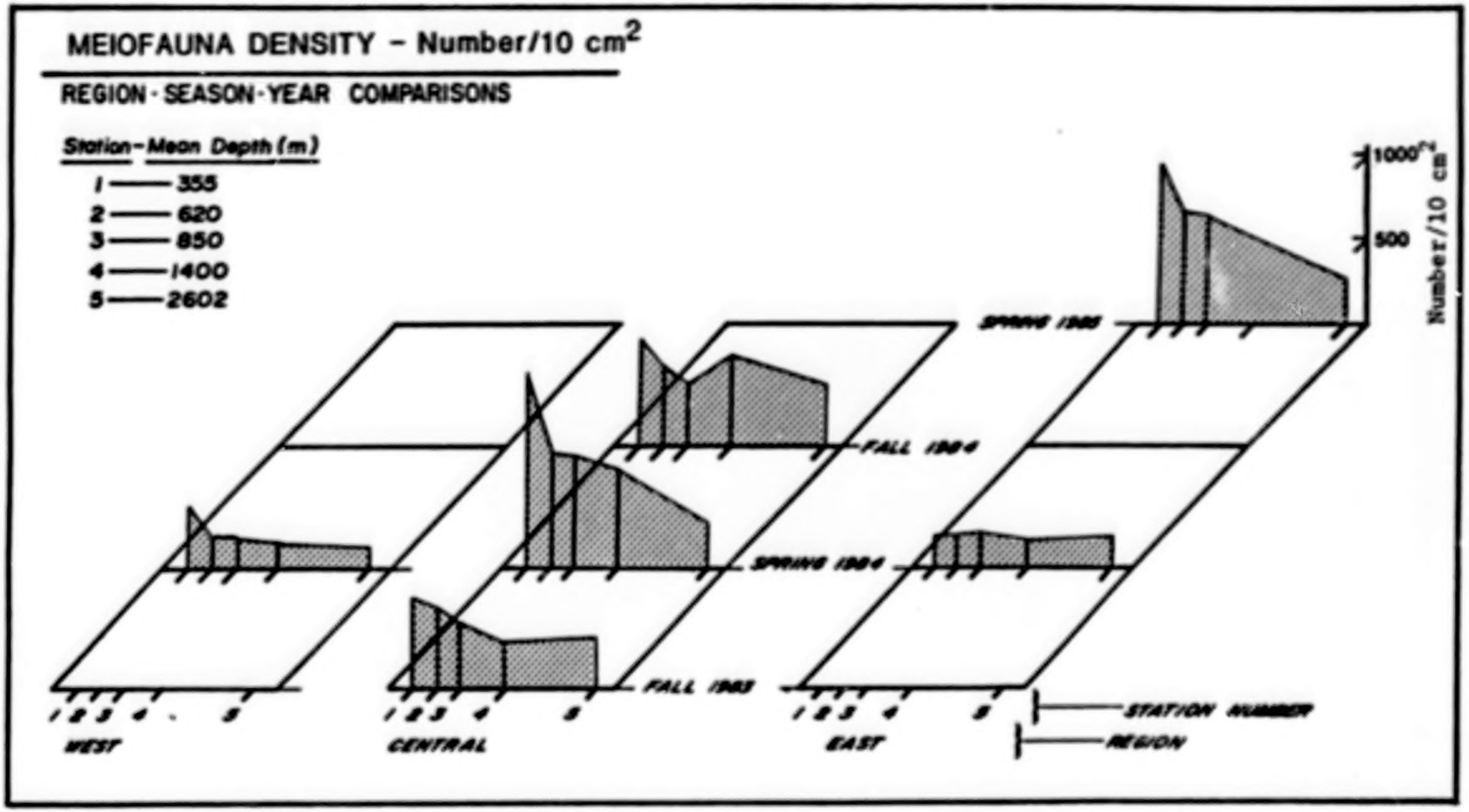

Figure 1. Analysis design diagram for region, season and year comparisons based upon samples taken at selected depths. Each tick mark represents the sample locations in time and space.

"zones" (Fig. 2), namely (1) the Shelf-Slope Transition Zone (150 to 450 m); (2) Horizon A of the Archibenthal Zone (475-740 m); (3) Horizon B of the Archibenthic Zone (775-950 m); (4) the Upper Abyssal Zone (975-2250 m); and (5) the Mesoabyssal Zone, Horizon C (2275-2700 m). The purpose here was not to either prove or disprove the concept of zonation versus a continuation of change with depth, but rather to evaluate the predictive value of the Pequegnat (1983) zonation scheme.

The same five stations on the Central Transect were sampled in fall 1983, spring 1984 and fall 1984. On the spring 1984 cruise, the same depth intervals sampled on the Central Transect were sampled on both an Eastern and Western Gulf transect, and in spring 1985 the stations comprising the Eastern Transect were resampled. The design thus allows a sequence of specific contrasts, proceeding from comparisons by region, to season within region, to year within season to depth patterns within region, season and year. Our basic depth comparison strategy will be to first contrast the Shelf/Slope Transition station to the deeper slope stations. The next basic division will be to contrast variables for stations located in depths shallower than 1000 m to those located deeper than 1000 m. This depth, or thereabouts, has long been viewed as a major break in the slope environment as it is here that light from the surface can no longer be distinguished and that temperature becomes uniformly cold ($\leq$ 4°C). The last contrasts will be made between the two depths corresponding to Pequegnat's (1983) defined assemblages within the shallow (< 1000 m) and deep (> 1000 m) categories. In contrast, according to Carney et al. (1983), we should find only (1) a distinct shelf fauna above 1000 m, (2) a distinct abyssal fauna below 2000 m, and (3) in between, an indistinct slope fauna that is partially obscured by immigration from the two larger areas shallower and deeper (Fig. 2).

The sampling design for Cruise III was focused towards evaluating and testing selected zonation hypotheses (e.g., Carney et al. 1983 versus Pequegnat 1983, Fig. 2). Twelve stations were sampled on the Central Transect at depths of 356, 492, 633, 881, 1017, 1191, 1428, 1465, 2100, 2518 and 2945. A site map is provided in Panel C of Figure 6, Section 2; an analysis design diagram is shown by Figure 3.

The first contrast will be to test the hypotheses of a real break at about 1000 m by comparing data taken at the first four (356 to 881 m)

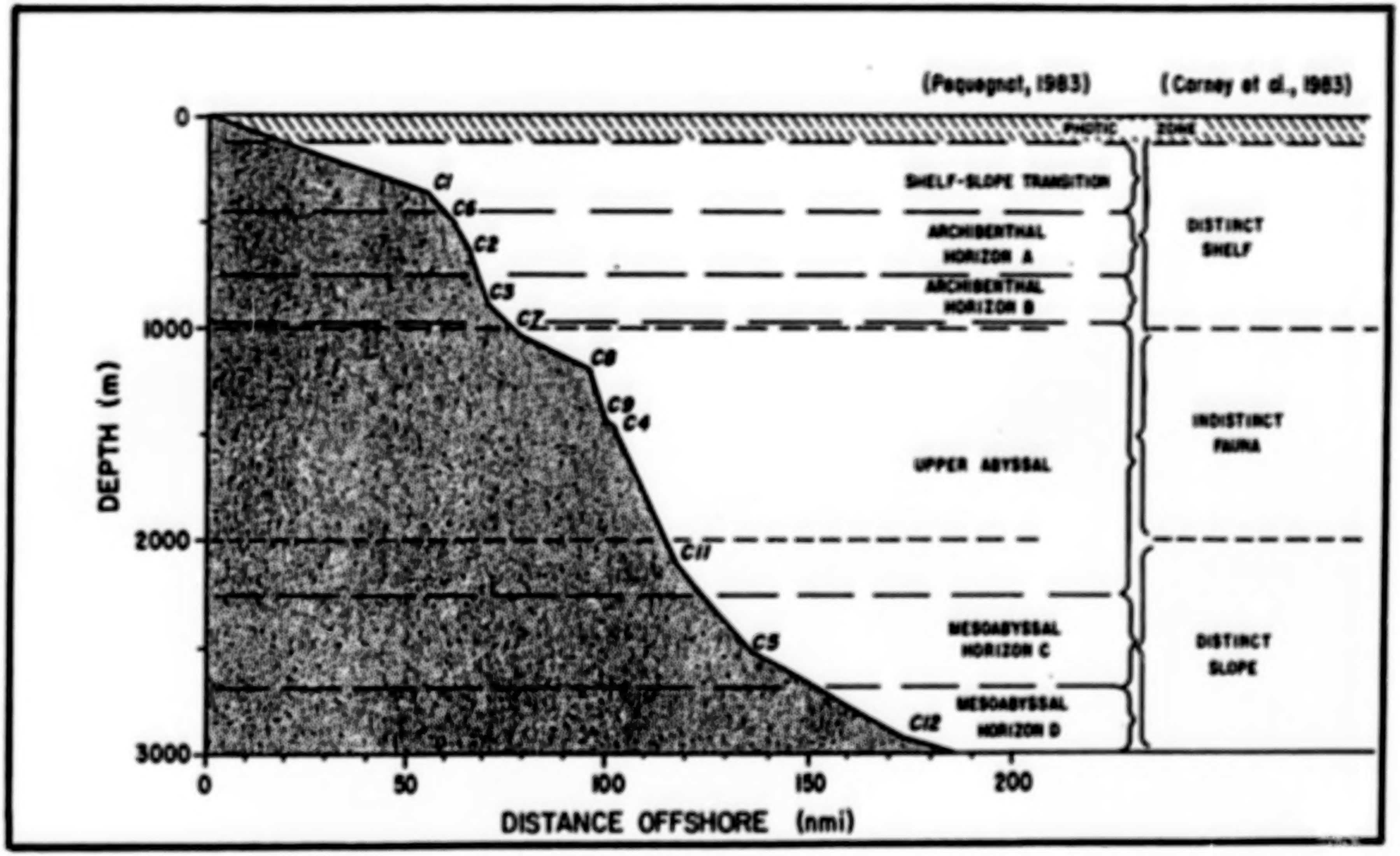

Figure 2. Two contrasting views of the expected faunal changes that might be observed on the continental slope of the northern Gulf of Mexico. C1–C12 represent stations sampled in this program during Fall 1985.

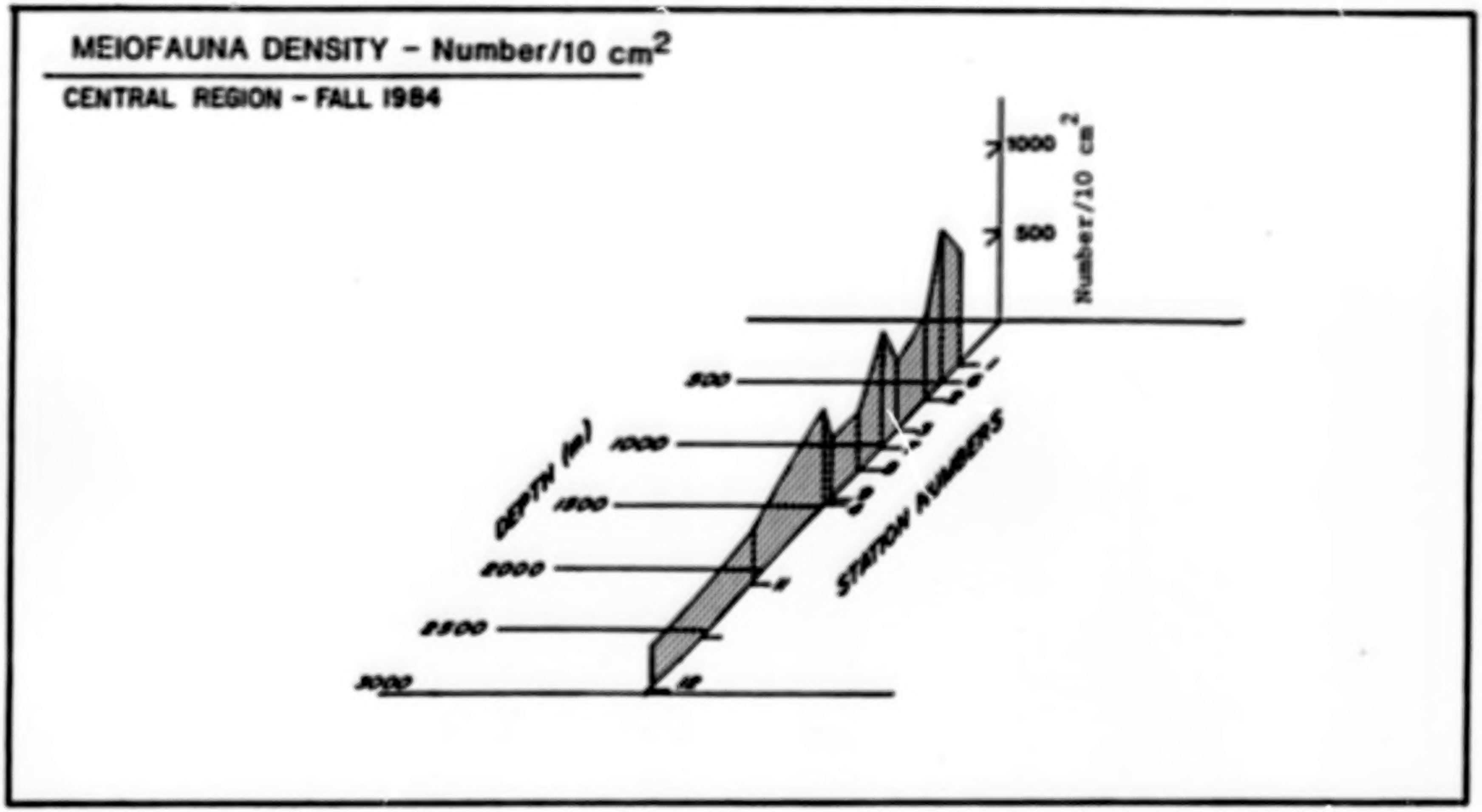

Figure 3. Analysis design diagram for zonation studies using density as the example response variable. See also Figure 2 for relationship of sampling stations to hypothesized faunal zones.

depths to data taken at the deeper depths (1017 to 2945 m). Within the shallow group of stations, we can then compare the hypothesized Shelf-Slope Transition Zone to the Archibenthal Zone and; lastly, between the two depths within each zone. Given the relatively even spacing among these more shallow stations, this sequence of contrasts should delineate between the dichotomous views of sharp faunal breaks (zones) versus a more conservative view of the nature of changes with depth.

The next contrast will be to compare variables at depths equating to Pequegnat's (1983) Upper Abyssal Zone versus those equating to his Mesoabyssal Zone; and for the latter, between the two hypothesized horizons. These should not be different according to the Carney et al. (1983) concept (Fig. 2).

At this point we will be left with the stations between 1000 and 2000 m. The first step will be to contrast the ~2000-m deep station which, although within the Upper Abyssal Zone, was widely separated from the other stations (• sampled depths). We will next compare the two shallower sites within the zone (881, 1017 m) to the deeper sites (1428, 1465 m), and then make comparisons between the individual depths within the two sets. The shallower set was more widely spread than the deeper set (see Figs. 2 and 3), thereby providing a test of the hypothesis that differences are mainly a function of distance between sites when placed along a depth gradient.

The sampling regimes for Cruises IV (Eastern Gulf) and V (Western Gulf) had similar objectives but for different regions. The overall goals were to sample along given isobaths to determine the degree of longitudinal or latitudinal variation as compared to depth variation, and to determine some of the sources of the observed variation by means of specific contrasts (e.g., sandy bottom areas versus silt and clay bottoms, petroleum seep areas versus non-seep areas, topographic attributes, etc.).

In the Eastern Gulf, the selected depths (Fig. 4, see also Fig. 6, Panel D, Section 2 for site map) were ~350 m (four stations), 625 m (six stations), 850 m (five stations), and 2900 m (one station). Once more, the first step will be to compare the Shelf-Slope Transition Zone (350-m deep stations) to "true" slope habitats. Next, the 2900-m deep station (Mesoabyssal, Horizon D) will be contrasted to those of the mid-slope Archibenthal Zone, Horizons A (625 m) and B (855 m). These contrasts will

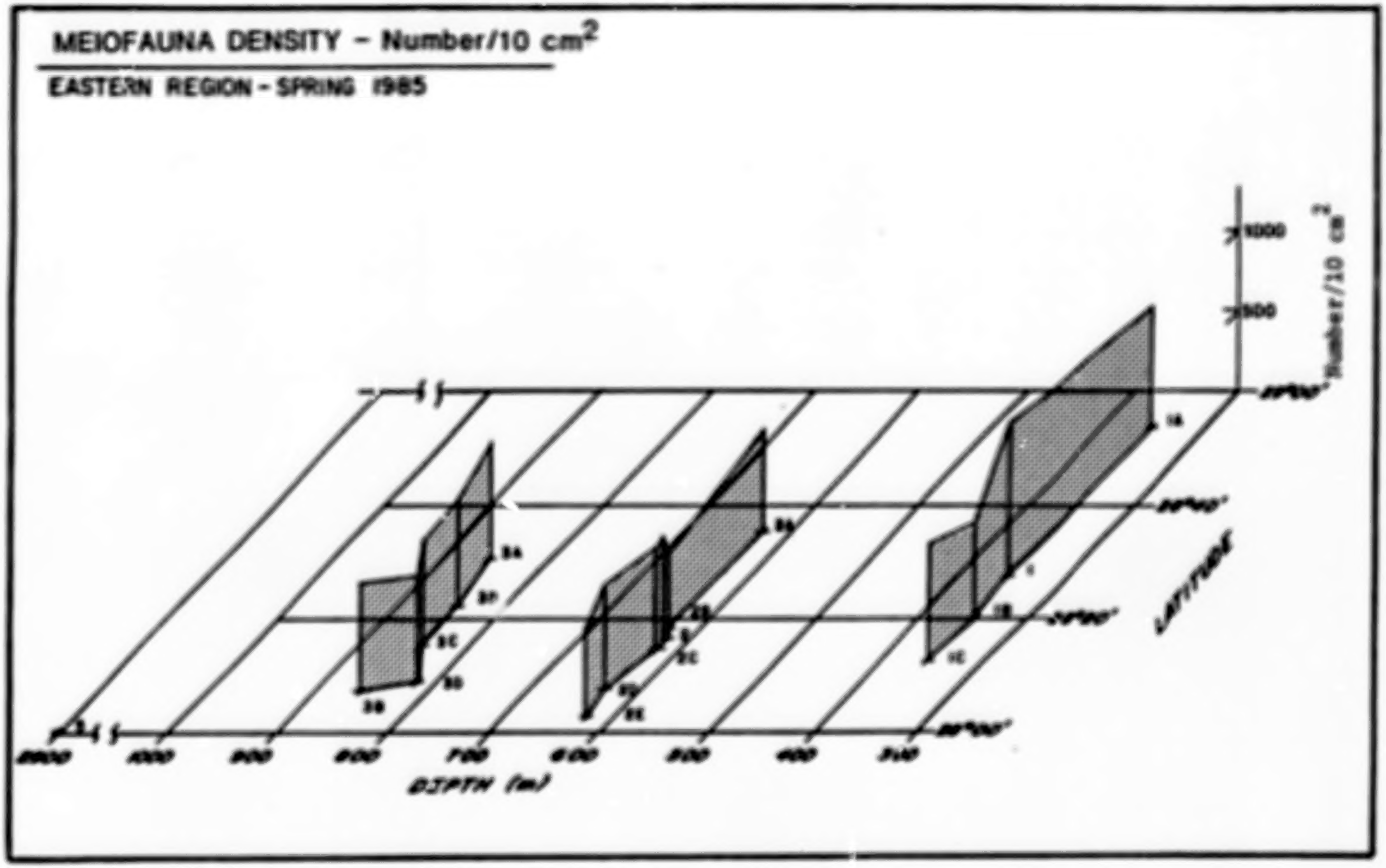

Figure 4. Analysis design diagram for samples taken in the Eastern Gulf in spring 1985 to examine latitudinal versus depth variation in samples taken at selected depths. Density is used as the example response variable.

be followed by a comparison of Horizons A and B within the Archibenthal Zone.

Within the Shelf-Slope Transition stations, one (E1A) was located on a silty-clay bottom whereas the others (E1B, E1 and E1C) were all sited, by design, on sand-silt-clay bottoms. This provides the basis for the initial contrast among these stations--the effects of sediment grain size. Next, the centrally-located station (E1) will be compared to the flanking stations E1B and E1C. And finally, the two distal stations will be contrasted. This sequence of tests will enable an evaluation of the effects of distance on observed biological differences along an isobath.

The placement of stations along the 625-m depth contours were all on the same sediment type, but three stations (2B, 2 and 2C) were tightly grouped as a core, with one station (2A) widely spaced from these to the northwest and two stations (2D and 2E) separated to the southeast. This provides the basis for the first contrast within this group of stations. Within the core group of stations, E2C was farthest removed from the other two and data from this station will be contrasted to data for E2 and E2B, which will then be compared to each other. Lastly, for this sequence of comparisons, the stations at the opposite ends of the transect will be compared, namely information for station E2A versus E2D and E2E combined, and then the latter versus one another. The results of these analyses should yield information enabling one to evaluate whether variation along an isobath is equivalent to variation observed on the vertical depth scale.

The station array for the 825-m deep stations enables an evaluation of the effects of latitude along an isobath. Here, stations E3B (28°02') and E3 (28°09') were the most southerly, and variables from these areas will be contrasted with information from stations E3C (28°15'), E3D (28°21') and E3A (28°29') treated as a group. Data from E3B and E3 will then be contrasted to each other followed by a contrast of data for E3A to E3C and E3D. Lastly, information for E3C and E3D will be contrasted as a measure of fine-scale latitudinal differences.

The isobathic sampling in the Western Gulf was conducted between the previously sampled Central and Western Transects, and stations included were given a WC (West-Central) prefix (see Fig. 6, Panel D, Section 2 for site map). An analysis design diagram is provided by Figure 5. Of the 12

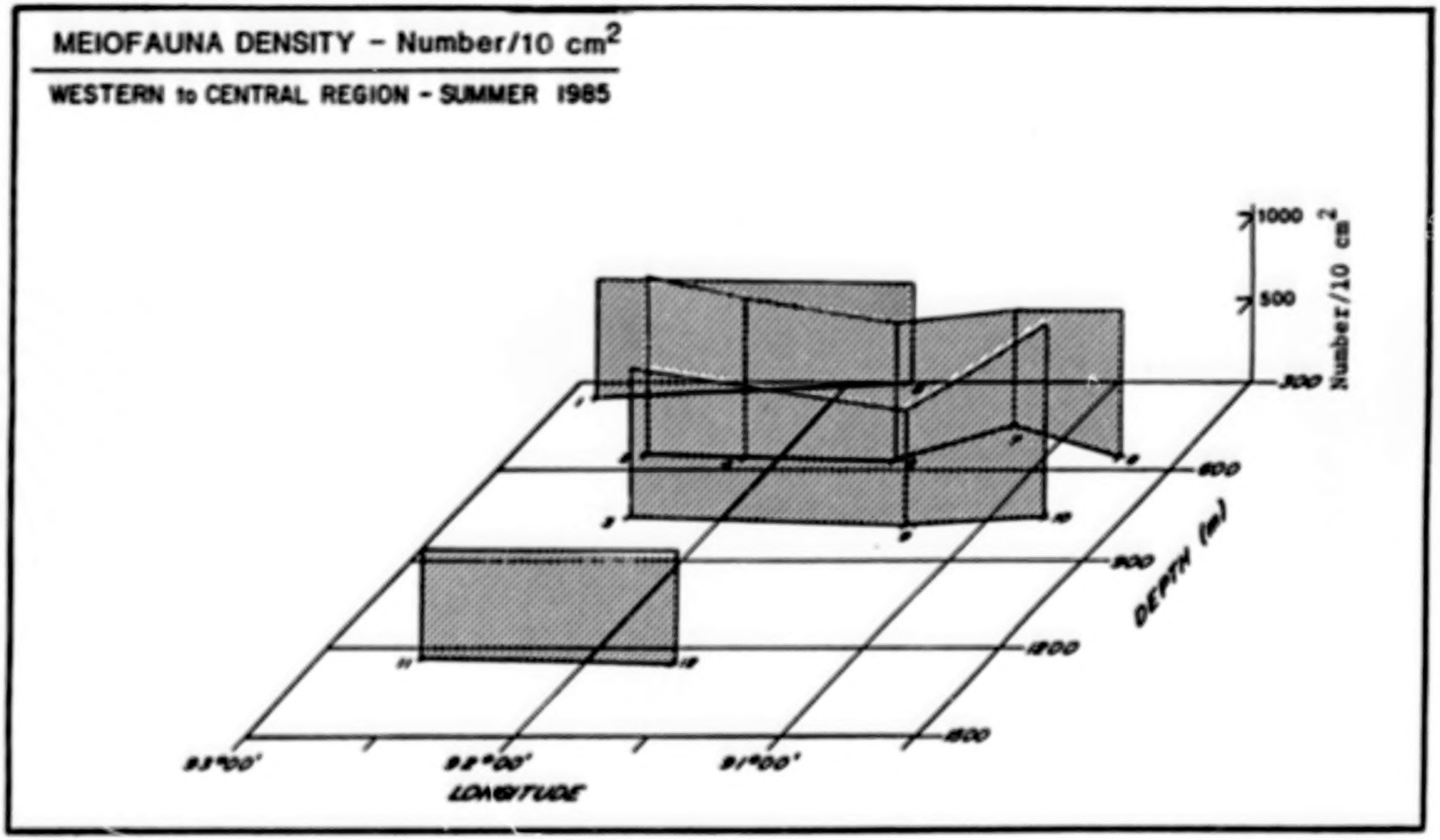

Figure 5. Analysis design diagram for samples taken between the Central and Western transects in summer 1985 to examine longitudinal versus depth variation in samples taken at selected depths. Density is used as the example response variable.

stations sampled, two (WC1 and WC5) were in the hypothesized Shelf-Slope Transition Zone (150-450 m); five (WC2, WC4, WC6, WC7 and WC8) were in Horizon A of the Archibenthal Zone (475-740 m); three (WC3, WC9 and WC10) were in Horizon B of the Archibenthal Zone (775 to 950 m); and two (WC11 and WC12) were in Horizon B of the Upper Abyssal Zone (975-2250 m), following Pequegnat (1983).

Following precedent, the first comparison will contrast the hypothesized Shelf-Slope Transition Zone to the stations deeper on the slope; and within the Shelf-Slope Transition Zone, a contrast of WC1 to WC5 enables an evaluation of the effects of sediment type (silty-clay versus sandy-clay). As before, we will then proceed to contrast the deepest stations (WC11, WC12) to the shallower stations on the slope proper (i.e., not including the transition zone). The contrast of WC11 (topographic low surrounded by shallower water) to WC12 (topographic high surrounded by deeper water) provides a direct examination of the effects of depth per se.

The next set of contrasts will be to address whether significant differences are apparent between the two hypothesized horizons within the Archibenthal Zone. Within Horizon A, a contrast of data for Stations WC6 and WC7 to the others in this zone (WC2, WC4 and WC8) provides an evaluation of areas with suspected petroleum seeps to areas believed to be devoid of any known petroleum seeps. The two seep areas will then be compared to each other; Station WC2 will be compared to WC4 and WC8; and WC4 will be compared to WC8. The latter contrasts will provide an estimate of longitudinal variation within the same depth range and sediment type. Within Horizon B, a contrast of WC3 to WC9 and WC10, and contrast of WC9 to WC10 will also provide an estimate of longitudinal variation within the same depth range and sediment type.

1.2.2 FINAL REPORT PLAN

In the Final Report environmental (hydrography, sediment characteristics, hydrocarbon chemistry) and some biological data will be integrated to show how the slope habitat differs among regions, depths, seasons and years. Differences will be determined by inspection as well as by more quantitative means such as Principal Components Analyses (PCA).

In our project design, we have up to 40 environmental or habitat variables that were measured as potential factors affecting biota. PCA enables one to transform a large original set of variables into a smaller set of combinations that account for most of the variance of the larger, original set. The purpose is thus to explain as much of the total variation in the data as possible, with as few of these factors as possible.

The outputs of PCA enables one to group entities (in our case, stations by depth, seasons and year) in terms of their physical/chemical attributes. This, in effect, provides an environmental classification against which we can compare results of various biological classifications of the same stations. The question being addressed by this approach is: Does the distribution and abundance patterns of biota on the slope correspond to environmental differences?

The biological analyses will first focus on each of the major taxonomic groups associated with soft bottom habitats, namely the meiofauna, macrofauna and megafauna, the latter of which were sampled using trawls as well as benthic photography.

The meiofauna section of the Final Report will describe the composition of the meiofauna by major group and numerical abundance patterns by season, region and depth. Differences will be evaluated by inspection because of the lack of any detailed taxonomic resolution. The abundance of meiofauna will be correlated to physical factors as well as to macrofauna abundance and biomass. Historically such contrasts have been used to depict overall community structure and a reflection of how this structure changes over depth (e.g., Thiel 1983). Based upon the above information, our findings will be compared to other regions, with any unique or unusual attributes of the Gulf meiofauna so identified.

The project meiofauna data set was the most complete of any project data set at the time this report was being prepared and the analyses presented in Section 4.1 are reasonably detailed. Nevertheless, the results presented herein are preliminary only, and do not represent the style and content which will be used in the Year 4 Final Report.

For each of the macrofauna and megafauna designations, the Final Report will first present an overview paper describing the species composition of the overall group and relative abundance patterns among species. Such descriptions will include species area and/or rarefaction curves as an index to assemblage structure. Seasonal and spatial (region and depth) patterns of diversity (Shannon-Wiener Index) will be described using Analysis of Variance (ANOVA) to detect significant differences and the contrast scheme detailed above (orthogoral contrasts) will be used to define the nature of the diversity differences by region, season and depth.

A number of diversity indices might be used, each having certain attributes and problems. All are influenced at least to some degree by sample size and all must be considered representative of the samples versus whole assemblages given known problems with sampling efficiencies of standard sampling devices (e.g., trawls and box corers) operated at great depths over different types of substrates. We have selected the Shannon-Wiener Index because (1) it has been demonstrated to be reasonably independent of sample size and, within limits, is normally distributed (Bowman et al. 1971) and, most importantly, (2) it has been previously used to define species diversity of the Continental Slope collections made in the northern Gulf of Mexico (Pequegnat 1983), allowing for direct comparisons.

The next step in the overview sections will be to apply cluster analysis techniques to biologically classify stations by region, season and depth for comparison, by inspection, to the classification scheme for the same stations yielded from PCA applied to physical/chemical attributes. Our cluster analysis approach will follow Grassle and Smith (1976) using a Normalized Expected Species Shared (NESS) as the similarity measure.

The findings of the described analyses will be compared to historical analyses of similar nature for other regions; and, in this context, any unusual attributes particular to the Gulf of Mexico will be identified. Also as part of the overview sections, we will identify the ecologically important or numerically dominant component groups within each of the macrofaunal and megafaunal designations. These groups will serve as subjects for a series of sections dealing with that group per se.

The same "community-type" analyses described above will be applied to the data for each major component group of the macro- and megafauna. In addition to these, we will also subject the species abundance data for depths and longitude to a chi-square analyses following Backus et al. (1965) and Gage (1986), designed to detect apparent faunal boundaries. By inspection and/or correlation, the findings will be related to distance between sampling sites.

In these sections of the Final Report, we will identify the most abundant species within the component groups and compare abundance patterns of these over time and space using ANOVA and orthogonal contrasts as defined above. An appropriate transformation will be applied to the data, if warranted, prior to the analyses. Likewise, correlation analyses will be conducted to determine the apparent associations of species abundance to physical/chemical attributes of the environment using data provided by the hydrography and sediment investigations. These discussions will also include a description of the present levels of hydrocarbons in animal tissues, as provided by the hydrocarbon chemistry studies.

Life-history accounts will be provided for numerically dominant or otherwise considered important species of megafauna. These will include discussion of food habits, size distribution, apparent growth patterns and length-weight relationships. For dominant macrofaunal species groups (e.g., the polychaetes) we will attempt to classify the populations by feeding type. All of this information is for the purpose of developing an overall conceptual model of the Continental Slope ecosystem. Some of the species accounts and feeding type information has already been developed and is included in this progress report as Attachments. The reader should bear in mind, however, that these accounts are not necessarily complete, and that no attempt is made herein to either interpret or integrate any of the information into a system context.

The Year 4 Final Report will also contain a section dealing with megafauna based upon our benthic photography surveys. While these results generally lack the taxonomic resolution required for many analyses, they have enabled an evaluation of the overall megafaunal densities estimated based upon trawling. Also, at least one very abundant species was photographed regularly that was never taken by trawling. These topics will be addressed in the Final Report, with the results, along with habitat observations, making major contribution to the system conceptual model. Many of the basic findings from the photography studies are presented in this report, but the reader is again forewarned, that little interpretation and no integration of the findings is attempted in this report.

As already mentioned above, none of the results of our chemosynthetic community investigations are addressed in this report, but a complete synthesis of information on these communities will appear in the Final Report, including results of project-specific studies.

The concluding section of the Year 4 Final Report will present a conceptual model of the Continental Slope ecosystem of the northern Gulf of Mexico, based upon an integration of all the program findings. In this section we will define the various types of assemblages that are represented and identify the energy sources and flows within and among assemblages. We will also identify areas of major uncertainties about the system and how these might be addressed by future studies.

1.3 GUIDE TO AND NATURE OF THIS REPORT

This Volume I of the Year 3 Annual Report provides a brief summary of some of the interim observations described in the Technical Report, Volume II. Volume III: Appendices, provides project data summaries.

During Year 3, submersible studies were conducted at selected sites where chemosynthetic seep communities were believed to be present. The results of these program studies will be provided as a separate report which, along with a synthesis of all other available information concerning Gulf of Mexico seep communities, will be incorporated in the Year 4 Final Report.

Some final introductory comments are in order here. Various sections of this report have been prepared by one or more of 12 individuals representing two institutions. Because of the preliminary and progress report nature of this volume, a major effort has not been given to standardization of data presentation, graphics and tables or consistency of text among sections. By program design, emphasis to this date has been placed upon quality assurance of the sample analyses and data compilation as opposed to data analysis, interpretation and the preparation of this report. With these observations in mind, we ask the reader's indulgence. However, despite the inconsistencies in style and content, we believe the discerning reader will find this report informative.

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2.0 STUDY AREA AND METHODS

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2.0 STUDY AREA AND METHODS

The Continental Slope Study was limited to waters north of 25°N, having depths between 200 and 3600 m. Stations were located in depths likely to "delineate faunal zonation or areas of transition" and in each of the MMS Western, Eastern, and Central Gulf of Mexico Lease Planning Areas.

One cruise was made to the Central Lease Planning Area during fall-winter of 1983, sampling of all three Lease Planning Areas during spring-summer of 1984, and intensive sampling of the Central Lease Planning Area was conducted during fall-winter of 1984. During spring-summer 1985, the Eastern and Central/Western Planning Areas were sampled. Sampling was conducted primarily along isobaths to evaluate vertical zonation in light of longitudinal variability.

2.1 STUDY AREA

The locations of sampling transects and stations are shown in Figure 6, and a summary of the rationale for their selection is outlined below. A few characteristics of each lease planning area, and the approximate positions of the original three transects that formed the nucleus of the sampling plan are:

1. Central Lease Planning Area - This transect extended across the slope in the vicinity of the Mississippi Trough, from approximately 28°20'N, 89°40'W to 26°40'N, 89°20'W. The area is characterized by extremely active sediment movement, relatively high terrigenous inputs, an absence of topographic features, and is occasionally bathed by the Loop Current.
2. Western Lease Planning Area - This transect extended across the slope just south of the Flower Garden Banks, from 27°25'N, 93°40'W to 25°50'N, 93°30'W. The area is characterized by te relatively sluggish circulation of the western Gulf, a number of pronounced topographic features, moderate to low declivity compared to the Mississippi

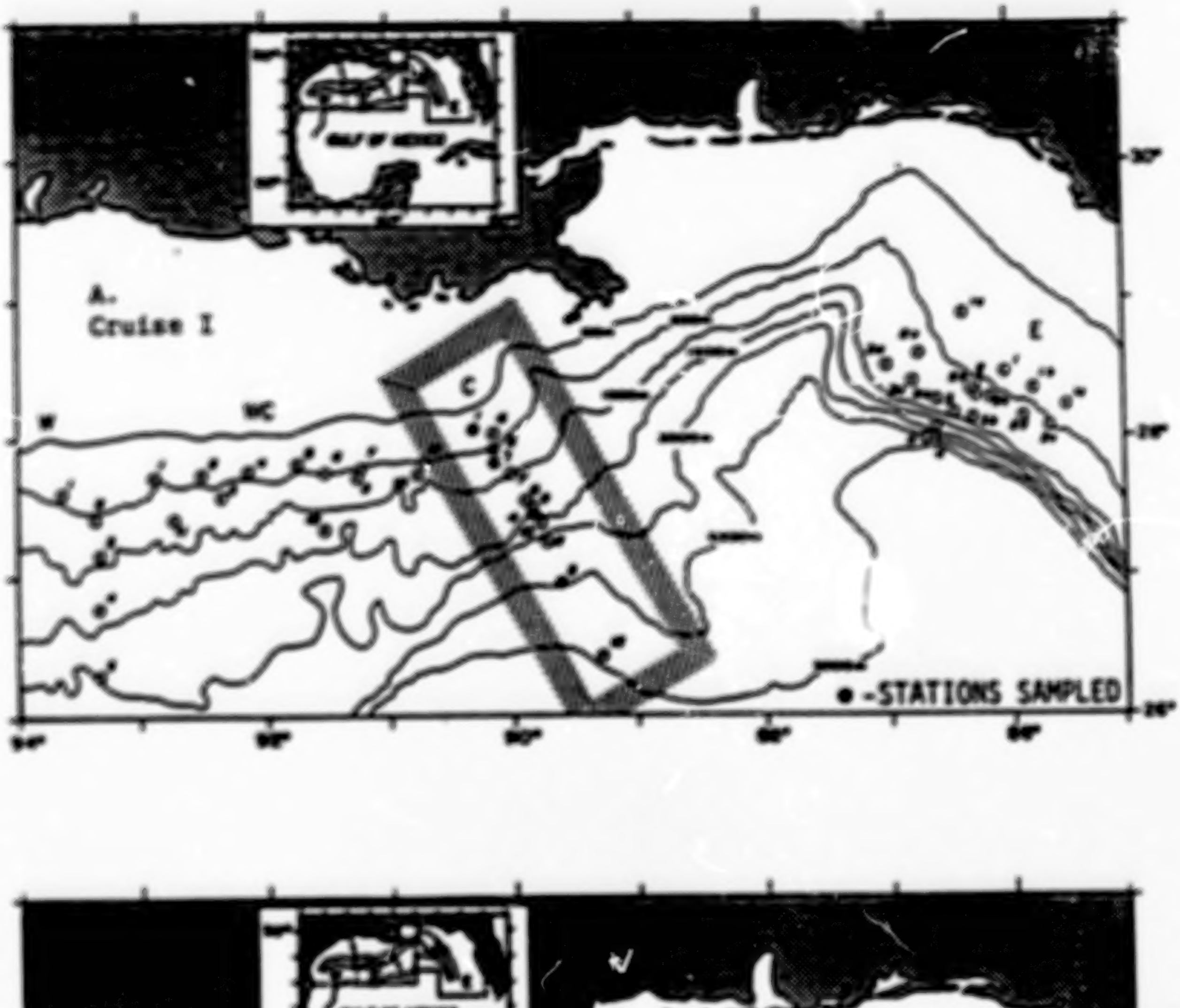

Figure 6. Stations sampled on each cruise.

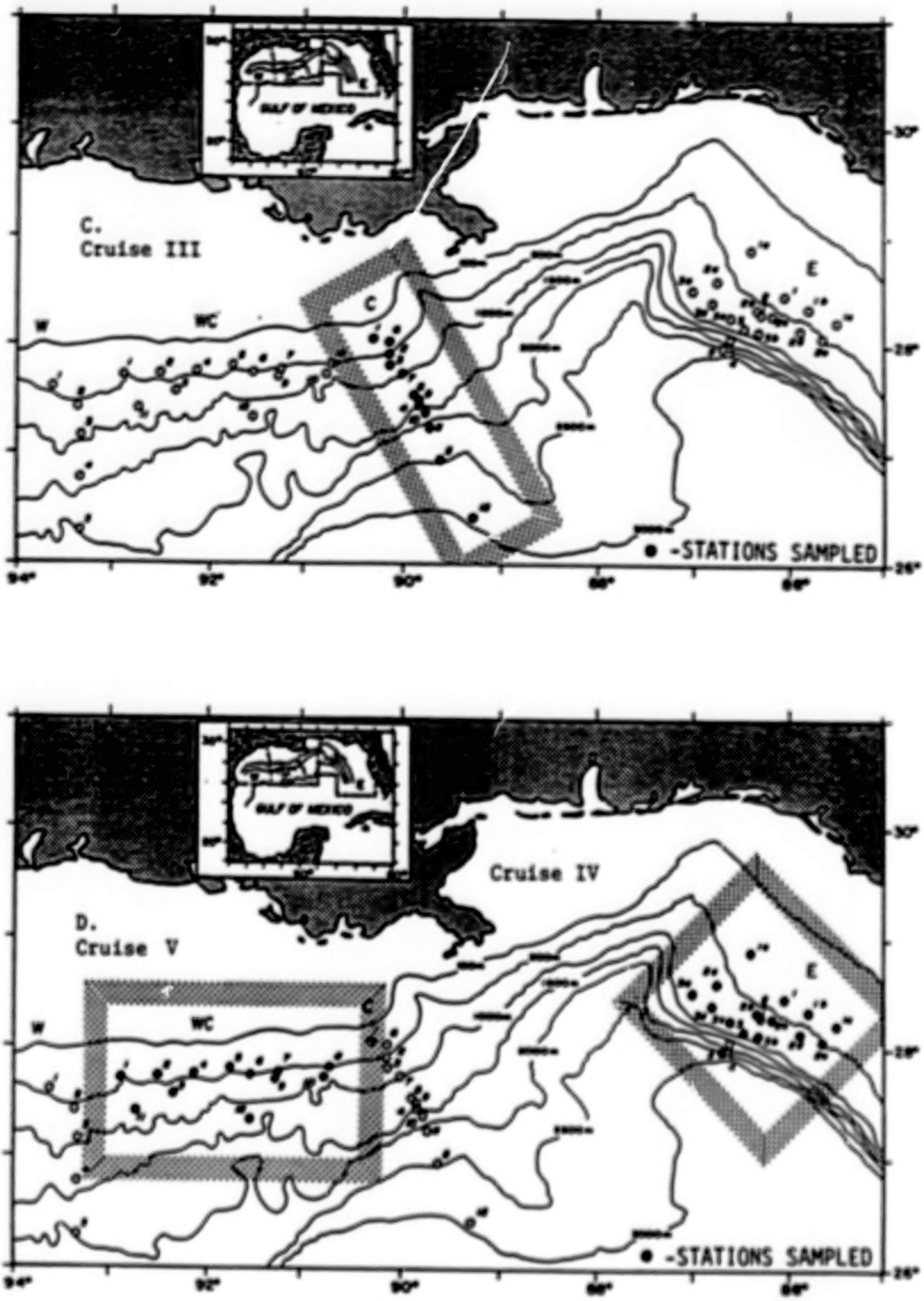

Figure 6. (cont'd).

Trough Transect. A fair amount of data is available from proximal areas.

3. Eastern Lease Planning Area - This transect crossed the Florida Escarpment from 27°40'N, 85°15'W to 27°30'N, 85°40'W. The area is characterized by high declivity (especially on the lower slope), a low rate of terrigenous input and sedimentation, and by moderate to strong currents along the face of the slope.

Station locations within each faunal zone were also influenced by water mass distribution and characteristics. The shallowest station in each transect was located towards the deeper end of the Shelf/Slope Transition Faunal Zone, below the zone of Gulf Common Water in Tropical Atlantic Central Water. Going down-slope, the next two stations were located in the Antarctic Intermediate Water mass, and the two deepest stations were in the Gulf Deep Water. Variation in water mass properties would be expected to be minimal at the deeper stations with the exception of events related to the passage of cold- and warm-core rings from the Loop Current.

2.2 CRUISES

On Cruise I, five stations at five different depths in the Central Gulf were sampled on the Central Transect during fall 1983 (Fig. 6A). The primary purpose of Cruise I was to provide a first look at the study area within previously-defined faunal zones over a wide depth range (300 to 2400 m), and provide data which could be used to refine future sampling and modify project hypotheses if necessary.

Cruise II, conducted during spring/summer 1984, extended the geographic coverage to the western and eastern regions of the Gulf, and re-sampled the stations occupied on Cruise I (Fig. 6B). Based on results of Cruise II, comparisons could be made among geographic areas and depths, as well as between seasons for stations on the Central Transect.

During Cruise III, the five original Central Transect stations were sampled again in fall 1984, along with seven additional stations (Fig. 6C). The seven new stations were located on the Central Transect at different depths from the first five stations. The locations for the additional stations were mainly in suspected transition areas and were based upon the advice of the Scientific Advisory Committee. Sampling the five original Central Transect stations allowed annual comparisons between the fall cruises of 1983 and 1984.

During the spring/summer 1985 Cruise IV, 16 stations were sampled near the Eastern Transect, including those previously occupied on the Eastern Transect on Cruise II (Fig. 6D). The new stations were grouped by depth at approximately 350 m (4 stations), 625 m (6 stations), 850 m (5 stations), and 2900 m (1 station). The intention was to examine depth-related differences in the context of observed variability along depth contours. Annual variability could also be studied by comparing the data from Stations E1, E2, E3, and E5 on Cruise IV to data from Cruise II, when the same stations were visited a year earlier.

Station locations for Cruise V (Fig. 6D), also conducted during spring/summer 1985, were chosen on the basis of several criteria. The area between the Western and Central Transects was subject to ongoing and expected future oil and gas exploration and development activities. Many sites were selected along depth contours in order to offer wide geographic coverage of the area and to document longitudinal variability in sediment and biological characteristics. Hydrocarbon seeps had also been reported in the area, and the associated biota had not been well documented. Two suspected areas of hydrocarbon seeps (Stations WC6 and WC7) were thus chosen to compare with probable "control" (non-seep) areas at comparable depths (Stations WC8 and WC2).

The sampling strategy described above permitted project scientists to make the following basic contrasts:

Contrast	Data Source
Seasonal variation by depth	Central Transect, Cruises I & II
Geographic variation by depth	Western, Central, and Eastern Transects, Cruise II
Annual variation by depth	Central Transect, Cruises I & III

Contrast	Data Source
Zonation patterns	Central Transect, Cruise III, plus data from all other cruises
Variation within depths, Western Gulf	West-Central Transect, Cruise V
Variation within depths, Eastern Gulf	Eastern Transect, Cruise IV

2.3 METHODS

2.3.1 FIELD METHODS

2.3.1.1 Hydrographic Measurements

Continuous and discrete measurements of hydrographic parameters were obtained throughout the water column (surface to bottom) at five stations on each cruise. A Neil-Brown Mark III CTD/Rosette/Transmissometer System was used to obtain continuous data and discrete water samples. Continuous conductivity (salinity), temperature, depth, and transmission records were provided by the Neil-Brown CTD. A 12-bottle rosette attached to the CTD was used to collect at least 12 discrete water samples at each station. Bottles were spaced throughout the water column in order to delineate the major water masses at each site. The CTD/Rosette/ Transmissometer system was deployed with a pinger so that the cast could be safely lowered to within a few meters of the bottom. This was done in order to discern whether there were bottom nepheloid layers at each site.

Continuous Measurements

The shipboard Neil-Brown CTD system consisted of a demodulator, digital display and digital-to-analog converters. Digital output of each scan (every 32 ms) was transmitted via armored cable to the shipboard unit in "TELETYPE" format using frequency-shift-keyed modulation designed to transmit up to 127 bytes (8 bits) per scan.

Transmission profiles were provided by a Sea Tech Inc. transmissometer interfaced to the CTD system. This instrument has a 25 cm light path with a light emitting diode with a wavelength of 660 nm as a light source. This instrument, with proper calibration, provides data with an error less than 0.5% transmission. It has a depth capability of ca. 2500 m.

The data from the CTD/transmissometer were stored both as a hard copy from an X-Y recorder and on magnetic tape. An HP-1000 computer was used aboard the R/V Gyre for data storage.

Discrete Measurements

Discrete measurements of temperature, salinity, dissolved oxygen, nutrients, and particulate organic carbon (POC) were obtained by collecting samples from PVC Niskin bottles mounted on a General Oceanics Rosette sampler. Subsamples for dissolved oxygen were drawn first. All the discrete measurements were performed at sea. Measurements of temperature, salinity, and POC were all performed in duplicate. Ten percent of the oxygen and nutrient samples were also duplicated to establish sampling and analytical precision, and to assure data reliability.

2.3.1.2 Box Core Sampling

Box core samples were taken at each station to obtain material for macroinfauna and meiofauna identification; sediment grain size; carbonate; total organic carbon; carbon isotopes; and hydrocarbons. Six replicate samples were taken at each station, except on the Western and Eastern Transect stations during Cruise II, when only three replicates were taken per station. The replicates were then subdivided to provide material for the various types of analyses.

Box corers were deployed in yoked pairs, using a TAMU-modified version of the Gray-O'Hara modification of the J&O box corer. Under ideal conditions, only one cast was required to collect two replicates.

The box corer (Fig. 7) measured 24.5 x 24.5 x 44 cm. It was fitted with a hinged door to prevent washout of samples, and had up to 135 kg of ballast. The door was open until the device had penetrated the substrate, whereupon the jaws and the door closed. The amount of ballast was adjusted to ensure adequate substrate penetration.

The box corer contained six metal coring tubes, 43.5 cm long and 3.5 cm in internal diameter. During Cruise I, these tubes were mounted in three pairs on a wire rack in the center of the box. This design was improved on successive cruises by mounting all six tubes against one wall of the box and securing them behind an aluminum partition that extended the full depth of the box. As each box corer came onboard, the overlying water was carefully siphoned into the macrofauna container, and the remaining subsamples processed according to their intended uses.

Sediments for Physical and Chemical Analyses

Undisturbed, uncontaminated sediment samples for analysis of hydrocarbons, grain size, carbonate, and total organic carbon were subsampled from the box core immediately after decantation of overlying water. The subsample for hydrocarbon, carbonate and TOC analyses were stored frozen in a glass jar, while the samples for grain size analysis were placed in whirl-pak bags and refrigerated. All samples were appropriately labeled.

Meiofauna

Four of the tubes were used for meiofauna samples. The top five centimeters of sediment in the meiofaunal tubes was extruded using a plunger and placed directly into a glass or plastic sample jar. An isotonic solution of magnesium sulfate was immediately added to narcotize meiofaunal organisms. After the sample had been in a cool place out of the sun for about 30 min, it was preserved by adding neutral buffered formalin with rose bengal until the contents reached a concentration of 5% formalin. The jar was gently shaken to achieve a uniform mixture of the preservative. Preserved samples were stored at ambient temperature.

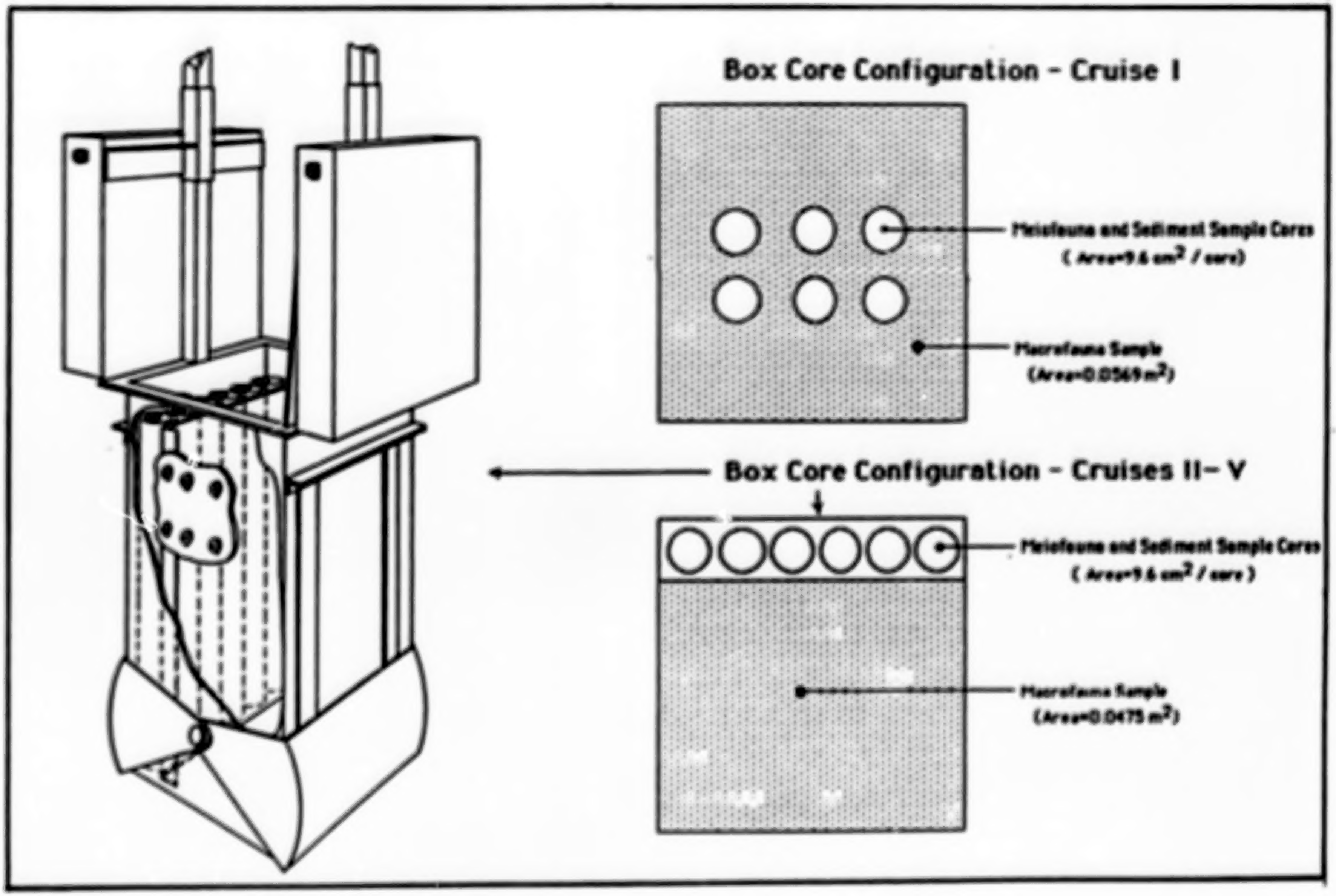
Box Core Configuration - Cruise I
Meiofauna and Sediment Sample Cores
(Area=9.6 cm² / core)
Macrofauna Sample
(Area=0.0569 m²)
Box Core Configuration - Cruises II- V
Meiofauna and Sediment Sample Cores
(Area=9.6 cm² / core)
Macrofauna Sample
(Area=0.0475 m²)

Figure 7. Box core and configuration of in situ subsampling tubes in the box corer.

Macrofauna

The remainder of the box core contents was removed to a depth of 20 cm and washed carefully on a 300-micron sieve with a gentle stream of cartridge filtered sea water. Material retained on the screen was placed in suitable containers, labeled, and narcotized in an isotonic magnesium sulfate solution. Following narcotization, organisms were preserved in a solution of 10% neutral buffered formalin in sea water, to which rose-bengal stain was added. These samples were stored in a cool place as soon as possible following collection.

2.3.1.3 Trawl Sampling (Megafauna)

Megafauna sampling was performed with a standard 9-m, semi-balloon otter trawl with 60-cm steel doors, 3.8-cm stretch mesh, and 1.3-cm cod end mesh. Target trawling times were one hour at stations shallower than 1300 m, and two or more hours at deeper stations. The amount of time on the bottom was arbitrarily measured as the time from winch brake application until the winch was started again for trawl retrieval. At a towing speed of one to three knots, a ratio of 3.5:1 between amount of wire out and the depth produced good samples.

The contents of each retrieved trawl was dumped into metal tubs. Fishes and invertebrates intended for hydrocarbon assays were quickly removed, photographed, and frozen. The remaining organisms were usually rough-sorted into three categories (fish, decapods, and "other"). They were then narcotized with isotonic magnesium sulfate if necessary, and preserved in 10% neutral buffered formalin in sea water.

2.3.1.4 Benthic Photography

Benthic photography samples were obtained with the use of a Benthos Model 372 deepsea camera fitted with a 28-mm lens (angle of view 35° x 48.5°), and equipped with a 200 watt-second Benthos strobe. On each visit to every station, the camera took 800 exposures of Kodak Ektachrome Professional 5936 film, ISO 200. Photographs were taken every eight seconds.

The photographic gear was mounted inside a protective framework similar to that of Woods Hole Oceanographic Institution's Mini-Angus (Fig. 8). The frame and its mounted components are called "BUCS" (Benthic Underwater Camera System) for convenience in this report. BUCS had a clock and altimeter that recorded the time and altitude above the bottom in the corner of each photograph. The altimeter had a resolution of ± 0.1 m.

BUCS was suspended from the vessel by a hydro wire, and allowed to drift near the bottom along transects 1500 to 5000 m long. Suspending BUCS in this way prevented skipping and bouncing on the bottom, thereby minimizing disturbance and reducing the chances of attracting or frightening animals away.

The plane of view was parallel to the bottom. Altitude was maintained by adjusting the vessel's winch in response to an acoustic signal transmitted by a 12 kHz bottom-finding pinger on BUCS. The signal was portrayed continuously on a strip chart recorder. Optimum camera altitude was approximately 2 m above the bottom, which produced shots that included 2.27 m^2 of the bottom. However, acceptable shots were obtained at altitudes from 0.7 m (0.27 m^2 area) to 4.0 m (9.09 m^2 area). At higher altitudes, larger areas were included in each shot, but image resolution was poorer; the converse was true at lower altitudes.

2.3.1.5 Quality Assurance and Quality Control (QA/QC)

Box Core Sampling

A concerted effort was made to obtain the highest quality samples. This effort included 1) using experienced and competent field biologists for sampling; 2) employing discrete criteria for quantifying the quality of each sample before it was accepted for on-board processing; 3) closely supervising sample handling, washing, narcotizing, and preliminary sorting; and 4) maintaining a sample tracking procedure to ensure proper chain-of-custody procedures.

In the field, the following criteria were used to judge whether a box core was acceptable:

1. The doors should be fully and properly closed;

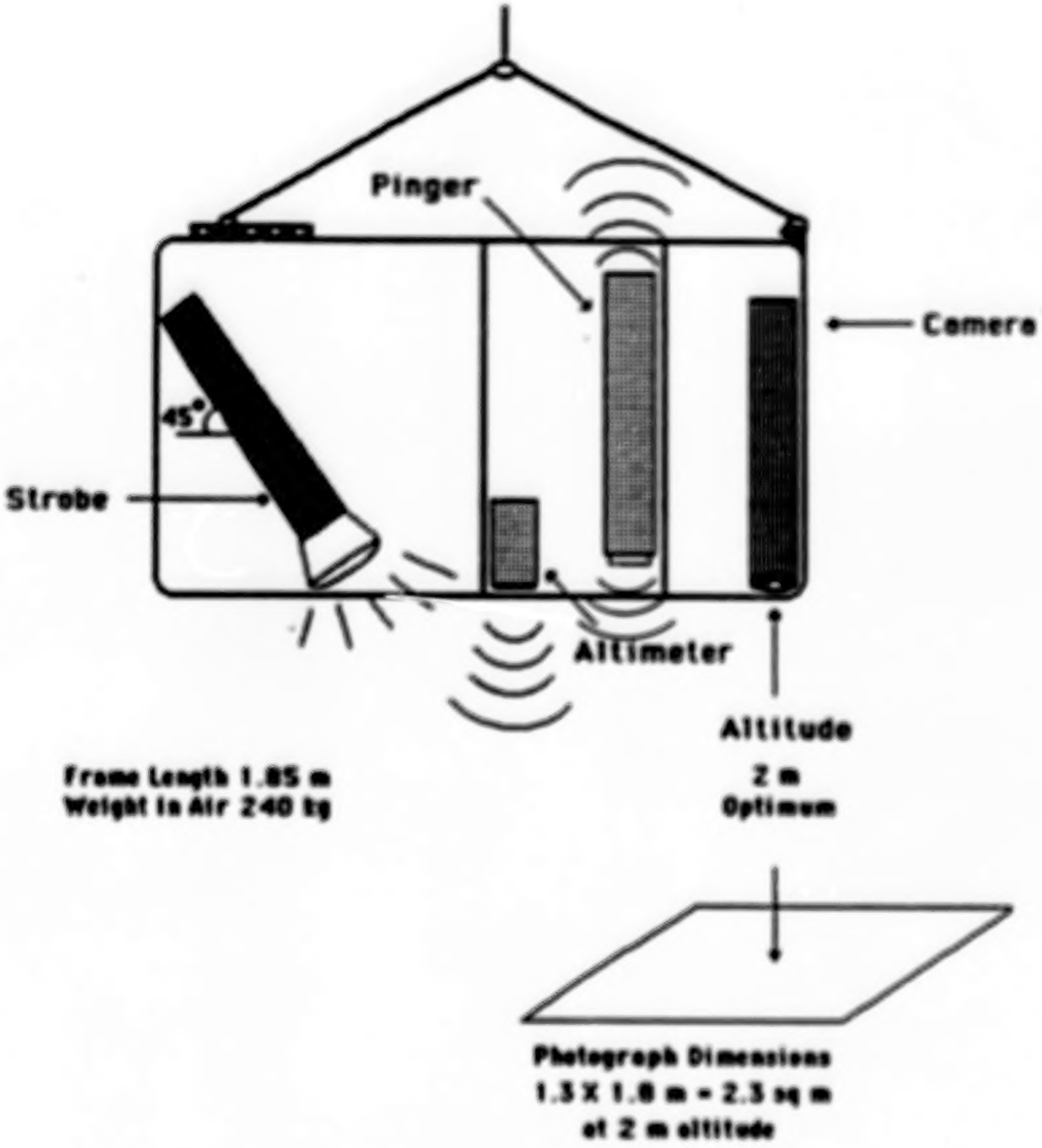

Figure 8. Schematic diagram of photographic system used for benthic photography.

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2. The sediment in the box should be covered with clear water, since cloudy water suggests mixing of water and sediment during retrieval; and
3. The sediment should be level within the box, since sloping sediment suggests non-vertical sediment penetration.

Coring continued at each station until the requisite number of replicates met these criteria.

Benthic Photography

All BUCS equipment was fully tested prior to each cruise. Fresh batteries were installed to power the 12 kHz bottom-finding pinger and camera data chamber. Nickel-cadmium batteries used in the high-intensity flash were drained and recharged to full capacity before every cruise, in order to prevent premature power loss during camera transects.

After each photographic transect was completed, a test strip of exposed film was developed while on station to confirm that no mechanical difficulties affecting the photography had occurred. The test strip was taken from the end of the 800-exposure roll, to determine whether or not the camera had exposed frames from the beginning to the end of the roll. If the test strip included an excessive number of poor shots, or if the sampling had to be aborted while underway, the photographic transect was repeated at that station. That proved necessary on only two occasions, out of 60 transects completed.

2.3.2 LABORATORY METHODS

Laboratory activities included both physical/chemical and hydrocarbon determinations for sediments and biota; carbon isotope analyses for sediments and biota; sorting, identifying, enumerating and weighing, and measuring biota as well as analyzing their gut contents; and the analyses of photographs for biota and lebensspuren.

2.3.2.1 Sediment Samples from Box Cores

Grain Size

Sediment grain size followed the laboratory procedure of Folk (1974). Samples were homogenized and treated with an aliquot of 30% hydrogen peroxide (H_2O_2) to oxidize organic matter, then washed with distilled water to remove soluble salts. Sodium hexametaphosphate was added to deflocculate each sample. The samples were then wet-sieved using a 62.5 micron (4.0 Ø) sieve to separate the gravel and sand from the silt-clay fraction.

The total gravel and sand fraction was oven dried (40°C) weighed, and sieved at half-phi intervals (-1.5, -1.0, -0.5, 0.0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, and 4.0). Each collected fraction was examined for aggregates, disaggregated if necessary, and reweighed by fraction to three significant figures.

The silt-clay fraction was analyzed for particle size distribution by the pipette (settling rate) method at 4.5, 5.0, 5.5, 6.0, 7.0, 8.0, 9.0, and 10.0 phi intervals.

Organic Carbon

Organic carbon determinations were made using a Leco WR-12 Total Carbon System. Sediment subsamples (0.2-0.5 g) were weighed into disposable 5 ml polystyrene beakers and treated with concentrated HCl to remove inorganic carbon (carbonate). Acid was added dropwise until no degassing was observed. The treated samples were then dried at 50°C in a recirculating oven for 24-36 hours to remove excess acid and moisture. After drying, the sample was quantitatively transferred to a sintered crucible. Iron accelerator and tin coated copper catalyst were added and analyzed by total combustion on the Leco instrument. Organic carbon was converted to CO_2 and analyzed with a non-dispersive infrared spectrophotometer. Blanks and standards were run on a daily basis. All samples were analyzed in duplicate and averaged. Periodically samples were combusted at >800°C in a high vacuum, Craig-type combustion system as a check on the combustion efficiency of the Leco system.

Carbonate Carbon

Carbonate carbon was determined for the same freeze-dried, homogenized sediment samples that were used for organic carbon and hydrocarbon determinations. Carbonate carbon in Cruise I samples was determined by difference between total carbon and carbonate-free (organic) carbon, using the Leco WR-12 Total Carbon System. For samples from Cruise II, carbonate carbon was determined directly by acidification in a carrier stream, followed by infrared detection.

Carbon Isotope Analyses

Carbon isotope analyses were performed on sediments and selected organisms to determine their food source. Stable carbon isotopes have been shown to be useful in delineating the flow of carbon through ecosystems since there is considerable evidence for minimal carbon isotopic fractionation along marine food chains (Parker 1964, Degens et al. 1968, DeNiro and Epstein 1978). Plants preferentially assimilate ^{12}C over ^{13}C during photosynthesis, and the degree of ^{13}C fractionation in plants is dependent on the biochemical pathway used for carbon fixation. Photosynthetically derived carbon from marine algae generally have carbon isotopic values ranging from -19 to -21 ppt. Carbon from terrestrial sources is generally at least 7 ppt lighter (more negative) due to the uptake of CO_2 as opposed to bicarbonate in the sea. However, there are other pathways that can contribute to variations in the organic carbon isotopic content of terrestrial plants.

Organisms that feed on photosynthetically derived carbon from marine algae have carbon isotopic values in the same range as the plankton (-19 to -21 ppt). However, tissue from mussels recovered at the Pacific vents have delta ^{13}C values near -33 ppt (Rau 1981, Rau and Hedges 1979, Williams et al. 1981). The vent communities of the Pacific are based on chemautotrophic bacteria that gain energy from the oxidation of hydrogen sulfide (Karl et al. 1980). In turn, the associated filter feeding organisms feeding on these isotopically light bacteria have similar isotopic values.

Stable carbon isotopes (delta ^{13}C values) were determined on freeze-dried sediment organic carbon and tissue samples. The stable carbon isotopic CO_2 composition derived from combustion of the organic matter was determined on a Nuclide Corporation six inch, 60° sector, isotope ratio mass spectrometer. The carbon isotope values are reported as per mil deviations from the Pee Dee Belemnite (PDB) standard:

$$\text{delta } ^{13}C = [(^{13}C/^{12}C) \text{ sample} - (^{13}C/^{12}C) \text{ std}/(^{13}C/^{12}C) \text{ std}] \times 1000$$

High Molecular Weight Hydrocarbons

This study involved the measurement of high molecular weight (HMW) hydrocarbons in megafauna (fishes and invertebrates) and sediments in samples collected on the Gulf of Mexico slope. Sediment samples were screened for aromatic hydrocarbon contamination using total scanning fluorescence, but primary detection and quantification of petroleum contamination was based on high resolution capillary gas chromatography and GC/MS/DS analysis. The purpose of the HWM hydrocarbon analyses were:

1. To determine the suite of HMW hydrocarbons present and their concentrations;
2. To determine probable sources of the HMW hydrocarbons as either thermogenic (from natural seepage or anthropogenic sources) or biogenic;
3. To determine the relationship betwaen HMW hydrocarbons and trophic levels;
4. To establish the extent of contamination with respect to distance from shore and/or offshore oil/gas production;
5. To determine the relationship, if any, between hydrocarbon chemistry, water depth, major current systems, and sediment physical characteristics; and
6. To compare the findings to known values for shallow water habitats in the Gulf of Mexico and subtropical U.S. Atlantic waters.

Protocols for analyzing both the sediment and benthic organisms were very similar (Figs. 9 and 10).

2.3.2.2 Biological Samples from Box Cores

Meiofauna

Meiofaunal samples were gently rinsed through a 300 micron sieve to remove larger organisms, and then through a 63 micron sieve. The material on the 63 micron sieve was then placed carefully--small amounts at a time--into a sorting dish partially filled with water. Individuals were sorted by major taxa under a dissecting scope, using an Irwin loop to transfer specimens to vials containing 70% ethanol. The vials were uniquely labeled according to collection date, location, replicate number etc., taxon, and the number of individuals contained in the vial. Biomass was estimated based upon published literature values for the size ranges of organisms in the samples (Faubel 1982, Rowe et al. 1974).

Macrofauna

Macrofaunal samples were gently rinsed with water to remove preservative, placed in a Petri dish--small amounts at a time--and examined under a dissecting microscope. Specimens were removed and sorted by major taxonomic group into labeled vials containing 70% ethanol. Wet-weight biomass was estimated for each taxonomic group based upon values reported in various published literature (Faubel 1982, Rowe et al. 1974)

All major taxonomic groups except Nematoda, Harpacticoida, Aplacophora, Scyphozoa (strobilas), Priapulida, and Acarina were given either to in-house or consulting taxonomic specialists for identificaion to the species level, if possible.

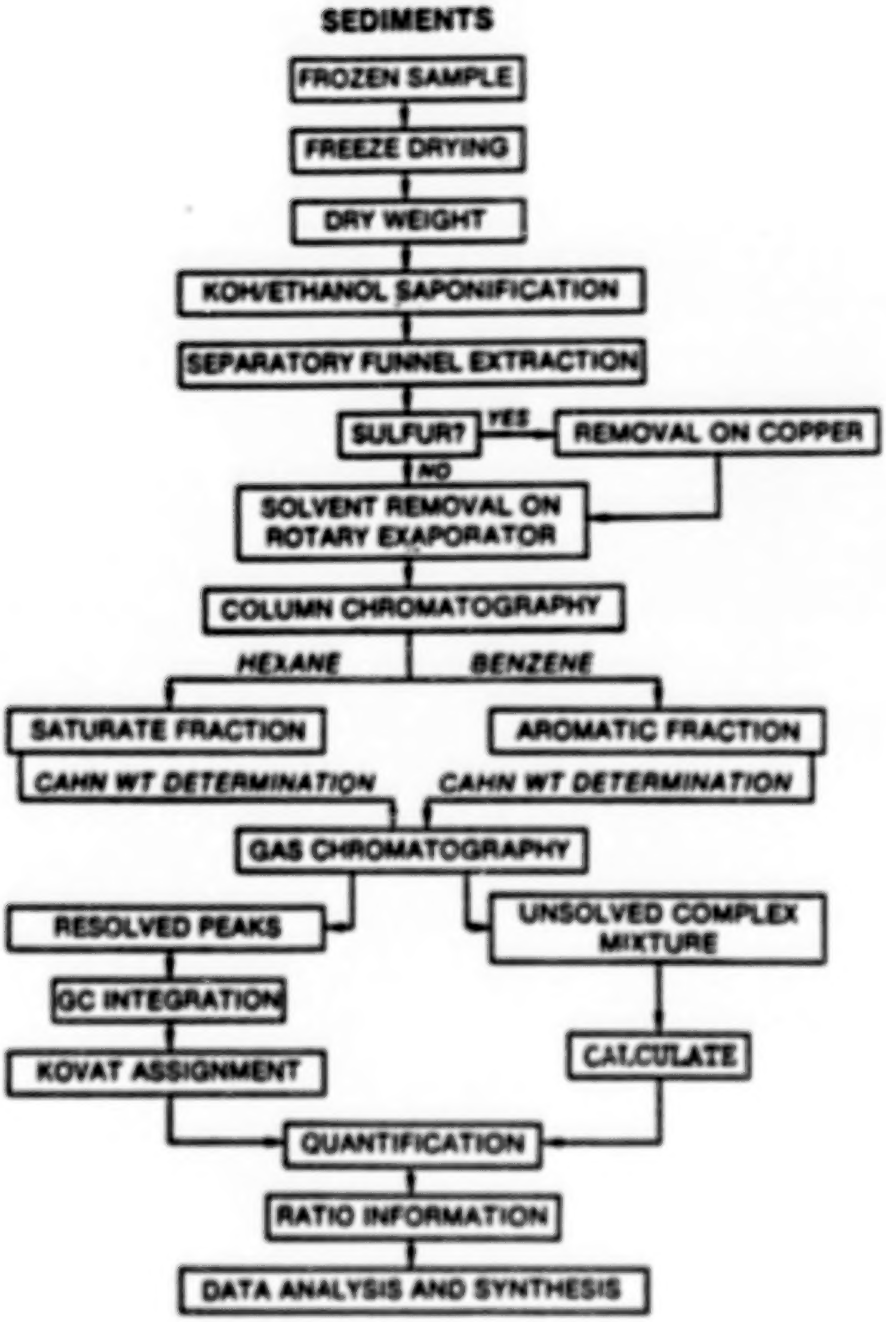

Figure 9. Sediment hydrocarbons analytical scheme.

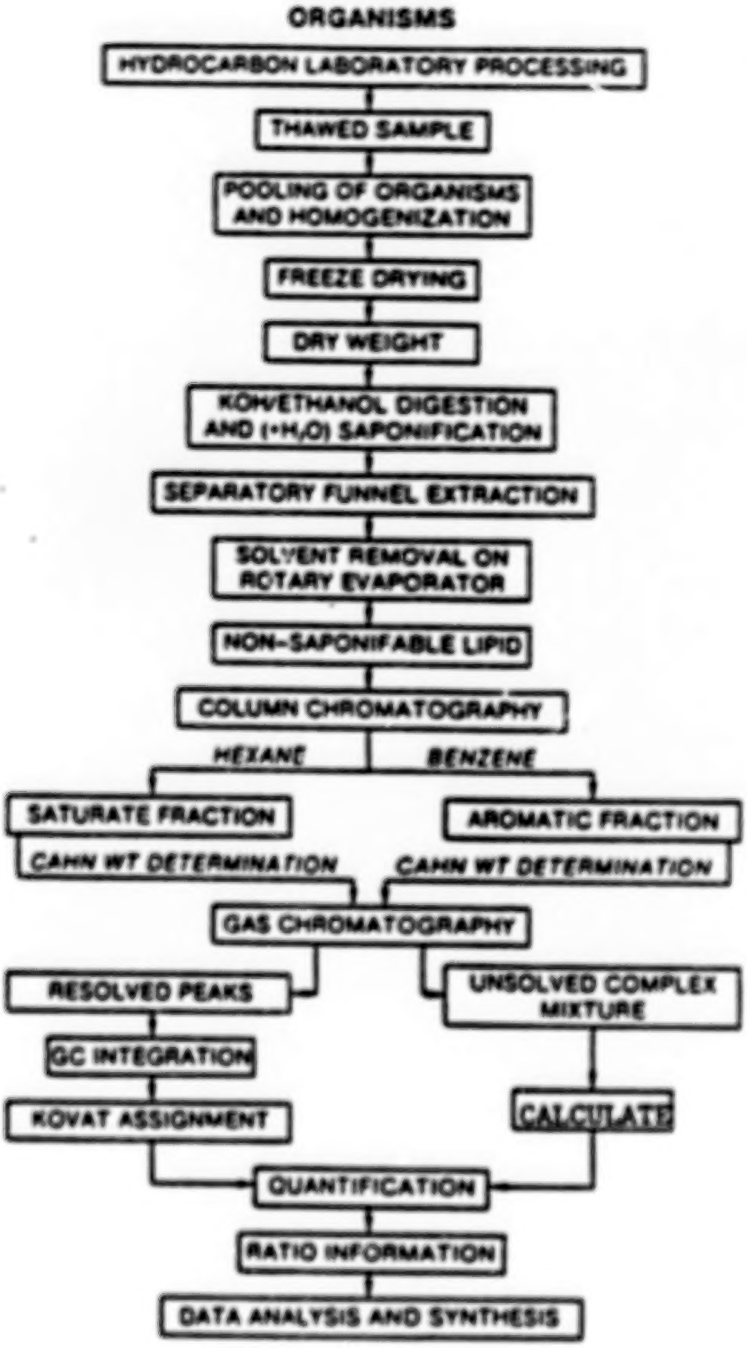

Figure 10. Hydrocarbon analysis scheme for organisms.

2.3.2.3 Trawl Samples (Megafauna)

Identification and Enumeration

Megafauna from the trawl samples were removed from the storage containers, rinsed to remove formalin, sorted, identified, and counted to major taxonomic group.

Size and Reproductive Condition

Fish and selected decapod species were weighed to the nearest 0.1 g (drained wet weight) and measured using the standard method for the taxonomic group in question. Where possible, sex and state of maturity were determined externally or internally if the specimen was examined for gut contents.

Gut Contents

Guts of selected representatives of common fishes were dissected and examined for assessment of food habits. Stomach contents were examined for the following parameters:

1. Percentage fullness, by volume;
2. Percentage composition by food item group, by volume;
3. Wet weight of each food item group; and
4. Number of individuals in each food item group.

High Molecular Weight Hydrocarbons

As mentioned in Section 2.3.2.1 (Sediment Samples from Box Cores), the organism hydrocarbon analytical scheme was very similar to the one used for sediments (Fig. 10). No fluorescence screening was performed. Since organisms do not generally contain large amounts of sulfur, desulfurization with copper was not necessaary. Three tissue types (liver, gonad, and muscle) were analyzed in fish specimens. Only muscle tissue was analyzed in other benthic fauna (shrimp, crabs, etc.).

Organisms are frozen at -20°C on board ship. Dissection was performed in a shore-based, clean laboratory. All utensils were pre-cleaned using procedures described in the sediment section. The target sample weight was 15 g wet weight. The method of digestion of tissues was identical to that used for sediment. The methods used in column separation, gas chromatography (GC), and gas chromatography/mass spectrometry (GC/MS) were also identical to those used in the sediment analytical scheme.

Carbon Isotopes

Carbon isotope methods are described in Section 2.3.2.1.

2.3.2.4 Benthic Photography

A procedure for detailed evaluation of benthic photographs was developed specifically for this project. Benthic photography samples obtained from photographic transects were processed on a digitizing pad driven by a microcomputer. The sizes of objects seen in the photographs were calculated from their distance from the camera (i.e. camera altitude, recorded in the corner of each shot) and the acceptance angles of the camera lens. Knowledge of the scale of the photographs made it possible to calculate the area shown in each photograph, and to measure the sizes of various features and biota. Each photo thus served as a quantitative quadrat sample of the survey site (Grassle et al. 1975).

The acceptance angles of the lenses were 35° (height) and 48.5° (width). The dimensions of one half of a quadrat can be calculated trigonometrically as:

1/2 quadrat height = altitude x tan 17.5°
1/2 quadrat width = altitude x tan 24.25°

The area included in a photograph is twice the product of these two numbers.

Processed film was projected through a modified bulk film projector and a front-silvered mirror mounted at a 45° angle (Fig. 11). The mirror reflected the photographic image onto a Houston Instruments Hi-Pad DT-11VA

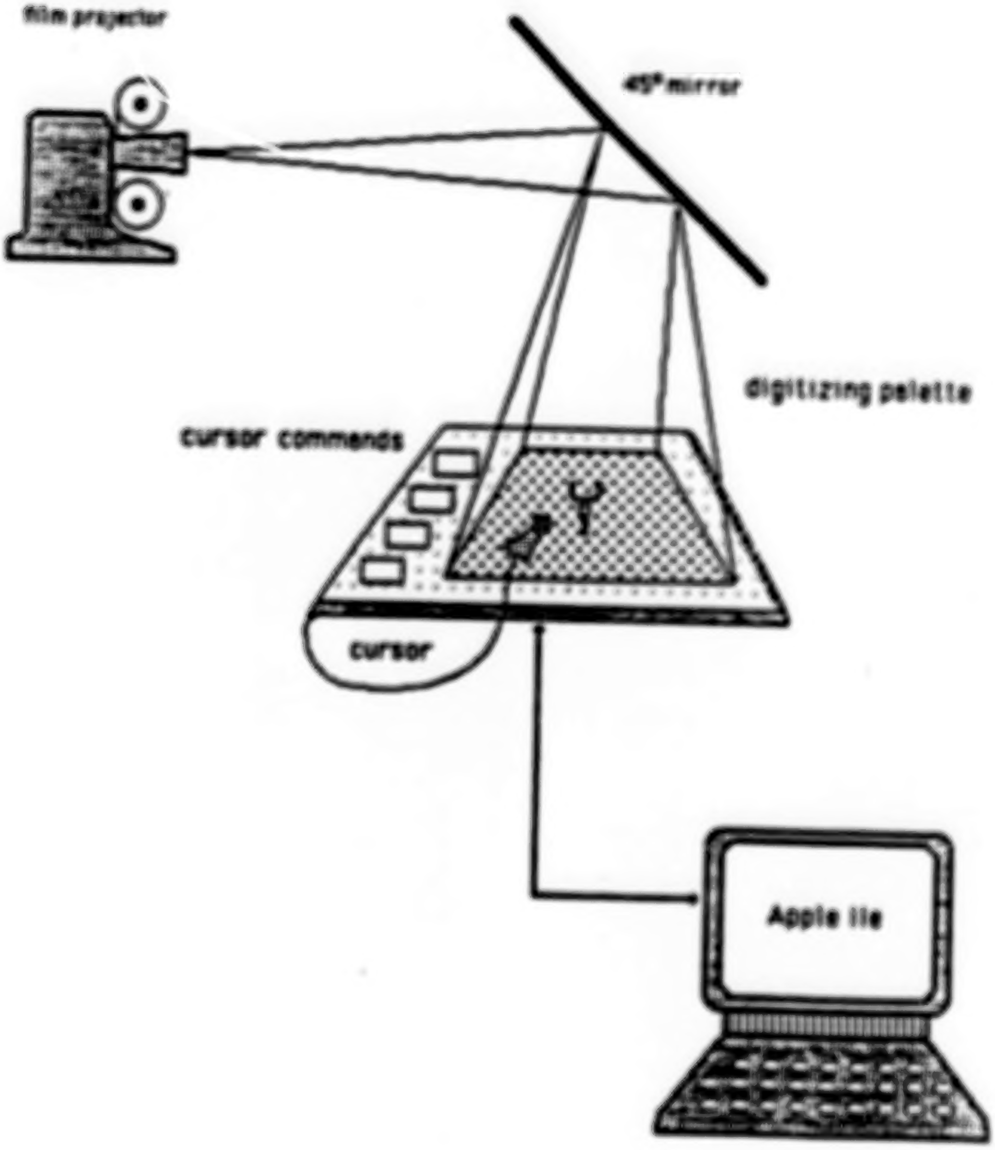

Figure 11. Schematic representation of digitizing apparatus used for processing benthic photographs.

digitizing pad connected to an Apple IIe microcomputer. The software for the computer was developed by LGL.

A subsample of either 100 frames (Cruise II) or 200 frames (Cruises III-IV) was selected from an entire roll from each station, using a systematic sampling technique described by Cochran (1977). The digitizer's cursor was then used to count and measure the subjects in the photograph. The operator had the ability to select any of three means to measure objects seen, depending on his judgement of the best representation of the object. He could determine whether the object was most appropriate to measure as a point, a straight line, or a closed figure. Each procedure utilized a different software routine, which could be activated with a cursor command.

2.3.3 DATA MANAGEMENT

The sequence of data management and analysis procedures used by LGL is shown in Figure 12. Most of the project data comes to the data management group on coding forms which were designed by the data manager and key project personnel at the outset of the program before any data were collected. Field and laboratory data were coded onto these data forms by laboratory personnel and then processed. Once validated, data were submitted to NODC.

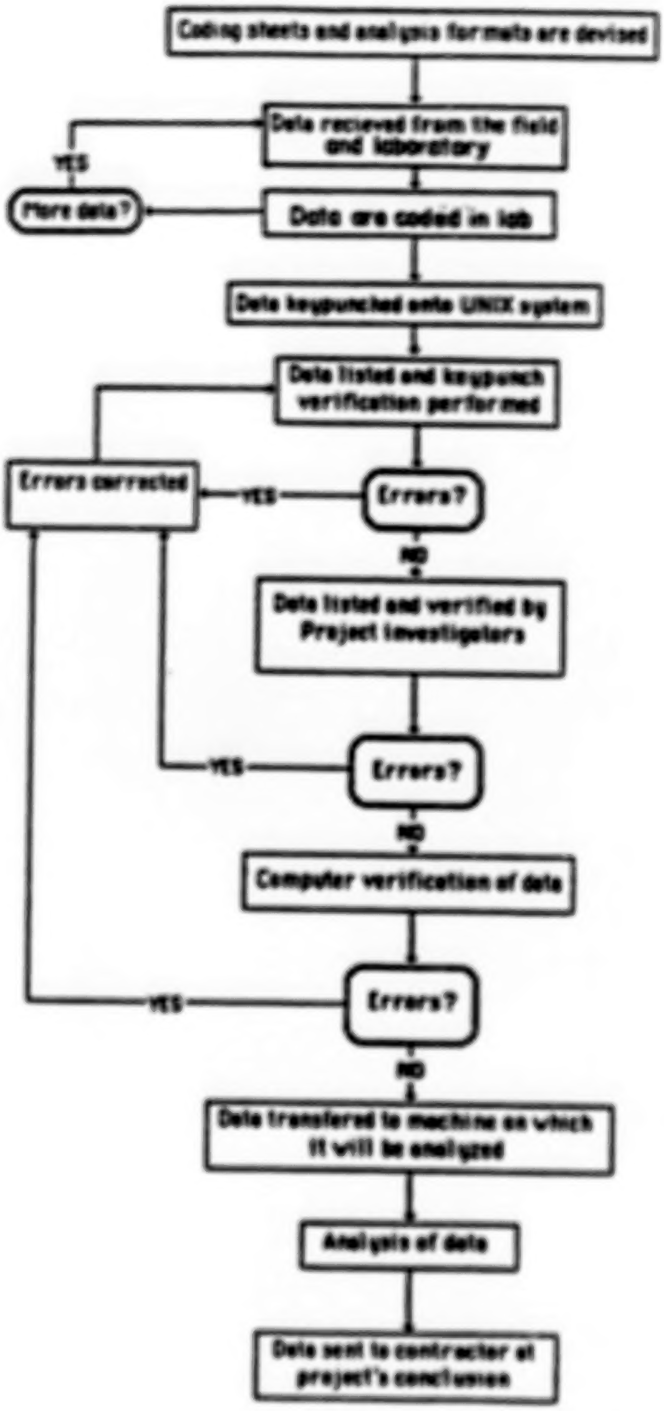
Coding sheets and analysis formats are devised
Data recieved from the field and laboratory
YES
More data?
Data are coded in lab
Data keypunched onto UNIX system
Data listed and keypunch verification performed
Errors corrected
YES
Errors?
NO
Data listed and verified by Project investigators
YES
Errors?
NO
Computer verification of data
YES
Errors?
NO
Data transfered to machine on which it will be analyzed
Analysis of data
Data sent to contractor at project's conclusion

Figure 12. Data flow sequence for Continental Slope Study.

3.0 PHYSICAL AND CHEMICAL RESULTS

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3.0 PHYSICAL AND CHEMICAL RESULTS

3.1 HYDROGRAPHY

Tabulated results of hydrographic profiles taken at five stations on each cruise are shown in Appendix B1 of Volume III of this report series. Depth related changes in physical and chemical constituents followed expected trends, with some variation by cruise and station location within the Gulf.

3.1.1 TEMPERATURE

From the surface (upper 25 m) to approximately 1300-1400 m depths temperature dropped from near 20° (19.01-25.08°C) to about 4.22-4.35°C at 1300-1400 m depth (Fig. 13). Below 1400 m temperatures remained constant within this low range. Between 300 and 1400 m, temperature variations by depth within transects was not great. On the central transect, Stations C1, C2, C3, C4 and C5 were each occupied three times (Cruise I-III). The maximum variations over the three cruises at representative depths of 300, 600, 900, and 1400 m were 2.59°, 0.78°, 0.29°, and 0.10°, respectively.

Similarly on Cruise IV in the eastern Gulf, profiles were measured at stations with bottom depths of 380, 665, 885, 915, and 2920 m. Temperature variations by depth along the transect were low; ranges were 1.93° (18.35-20.28°C) at 100 m; 1.72° (9.31-11.03°C) at 400 m; 0.68° (7.05-7.73°C) at 600 m and 0.16° (5.10-5.26°C) at 900 m.

On a large scale, temperature differences from the western to the eastern Gulf also showed only minor changes (Fig. 14). From the western to the eastern Gulf the most temperature variation by depth was only 0.49°C at 275-m depth.

3.1.2 SALINITY

Salinity profiles exhibited the characteristic pattern for the Gulf of Mexico (Fig. 13). Surface salinity ranged from about 35 to about 36.5 °/oo and increased with depth to about 100-200 m where the salinity maxima, characteristic of the core of the Gulf Common Water, is found

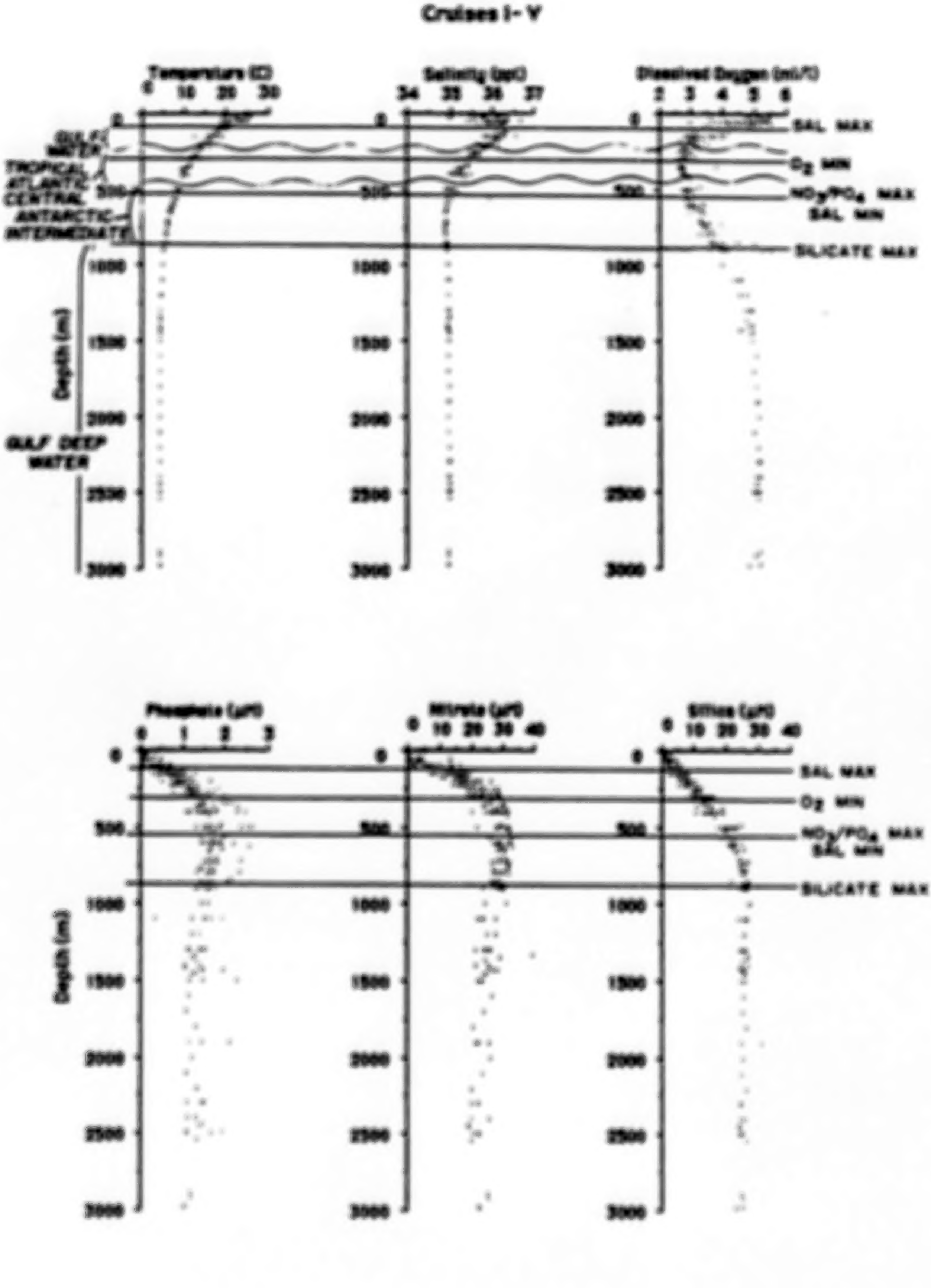

Figure 13. Hydrographic profiles, all cruises combined.

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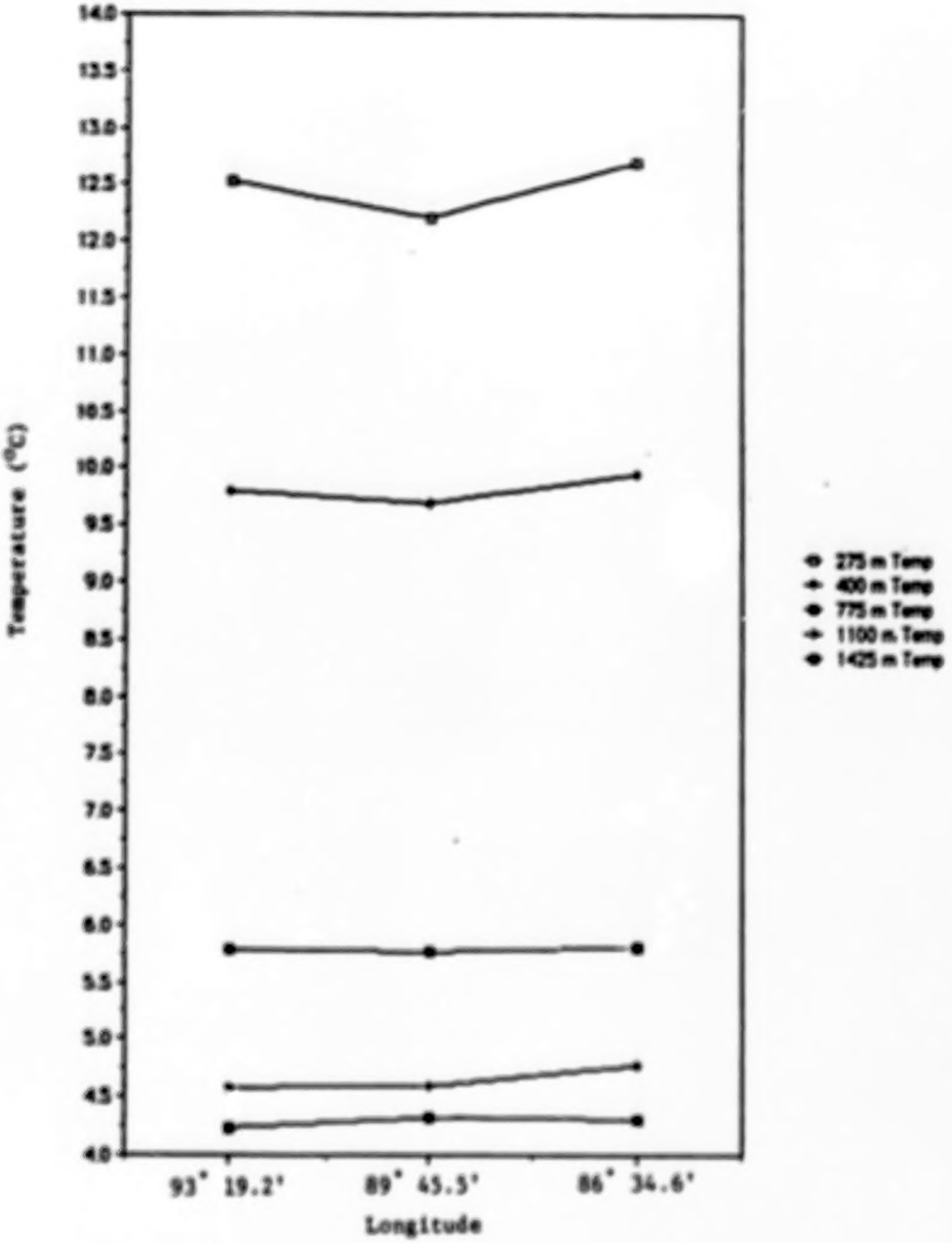

Figure 14. Variation in temperature at selected depths measured at 3 stations (W4, C4, E4) across the Gulf during Cruise II.

(Fig. 13). Below the salinity maxima, salinity decreased to a depth of about 600-800 m where the salinity minimum is located. The salinity minimum is used as an indicator of the core of the Antarctic Intermediate Water Mass.

Using the same depths that were used above to compare seasonal temperature differences by depth along the central transect stations during Cruises I-III, salinity showed the following variability for depths between 300 and 1400 m:

Depth	Extreme	Range
300 m	35.16-35.70 °/oo	0.54 °/oo
600 m	34.90-34.94	0.04
900 m	34.89-34.95	0.06
1400 m	34.94-34.98	0.04

Thus, less than 0.1 °/oo salinity variation was observed for any depth on the Central Transect over three cruises.

Longitudinal variations in salinity based on measurements taken during Cruise II at similar depths from stations in the western, central and eastern Gulf are shown in Figure 15. At 275 and 400 m salinity was slightly higher in the eastern Gulf, with the central Gulf station (C4) having the lowest salinity at these depths. (Extreme difference of 0.07 °/oo.) At 775 m and below (1100-1400 m) there was a slight but general decrease in salinity from west to east (less than 0.04 °/oo difference). These differences were less than the observed difference along the central transect at similar depths over three cruises for December 1983 to November 1984.

3.1.3 DISSOLVED OXYGEN

Dissolved oxygen concentration (Fig. 13) ranged from about 2.5 to 5.5 ml/l (= ~3.6-7.8 mg/l). These concentrations are not considered to be limiting to aerobic fauna found in the ocean. Dissolved oxygen concentrations were higher in the surface waters (<50 m) decreasing to the oxygen minimum layer (about 400 m depth), which is used to identify the Tropical Atlantic Central Water Mass. In the eastern Gulf, a secondary

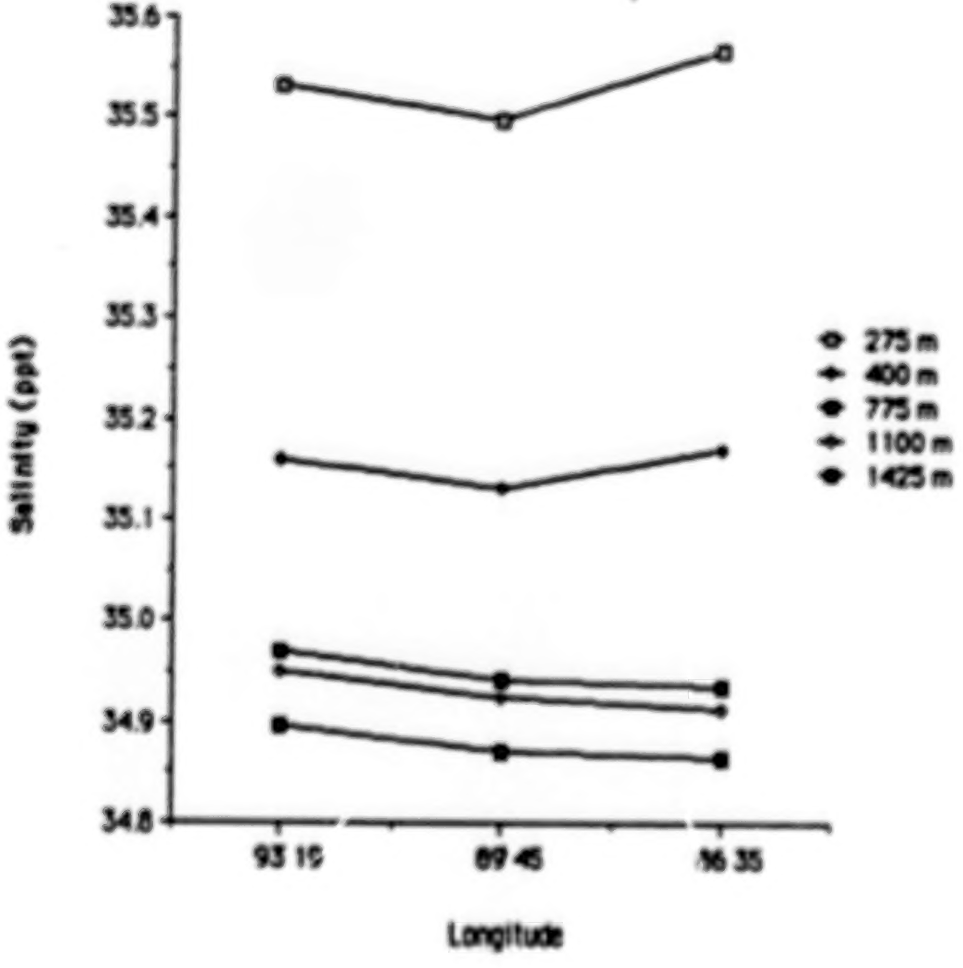

Figure 15. Variation in salinity at selected depths measured at 3 stations (W4, C4, E4) across the Gulf during Cruise II.

oxygen minimum layer at 150 to 300 m is sometimes found, associated with the Eastern Gulf Loop Current (Nowlin and McLellan 1967). This phenomenon was apparently present during Cruise II, on the eastern transect station E4, where two oxygen minima were observed (one at 174 and one at 400 m.

Below the oxygen minimum, D.O. concentrations increased to a depth of approximately 1500 m. From 1500 m to 2200 m dissolved oxygen concentrations remain relatively constant at approximately 5 ml/l. Station WC12 sampled on Cruise V produced some anomalous D.O. results although temperature and salinity profiles were normal. No explanation other than sample handling or analytical error have been postulated for these results, although there is no reason to expect these.

Across the Gulf, dissolved oxygen levels varied less than 0.2 ml/l at a given depth except for measurements made at 1400 m (Fig. 16). The 1400 m depth is an area of increasing D.O. levels and small-scale differences in depth of measurement would have more impact than measurements made at other depths.

3.1.4 NUTRIENTS

Nitrate, phosphate and silicate concentrations are used as indicators of Antarctic Intermediate and Gulf Deep Water Masses. The nitrate and phosphate maxima, which usually coincide along with the salinity minimum, delineate the core of Antarctic Intermediate Water while the silicate maximum marks the upper boundary of Gulf Deep Water (a mixture of North Atlantic Deep Water and Carribbean Midwater Masses).

Nitrate levels increased from near zero at the surface to ~30-33 μM at 500-700 m depths (Fig. 13). Below 500-700 m there was a gradual decrease to about 20 μM. Phosphate levels followed a similar pattern with maximum values of 2.0-2.6 μM (Fig. 13). Both nitrate and phosphate levels usually exhibit marked increases at about 100-200 m, probably a result of decreased photosynthetic activity.

On Cruise II, there was a general west to east increase in nitrate concentrations below 275 m with maximum values observed on the Central Transect (Fig. 17). Phosphate concentrations by depth were usually lower in the east with maximum values in the west or central transect depending on depth (Fig. 18).

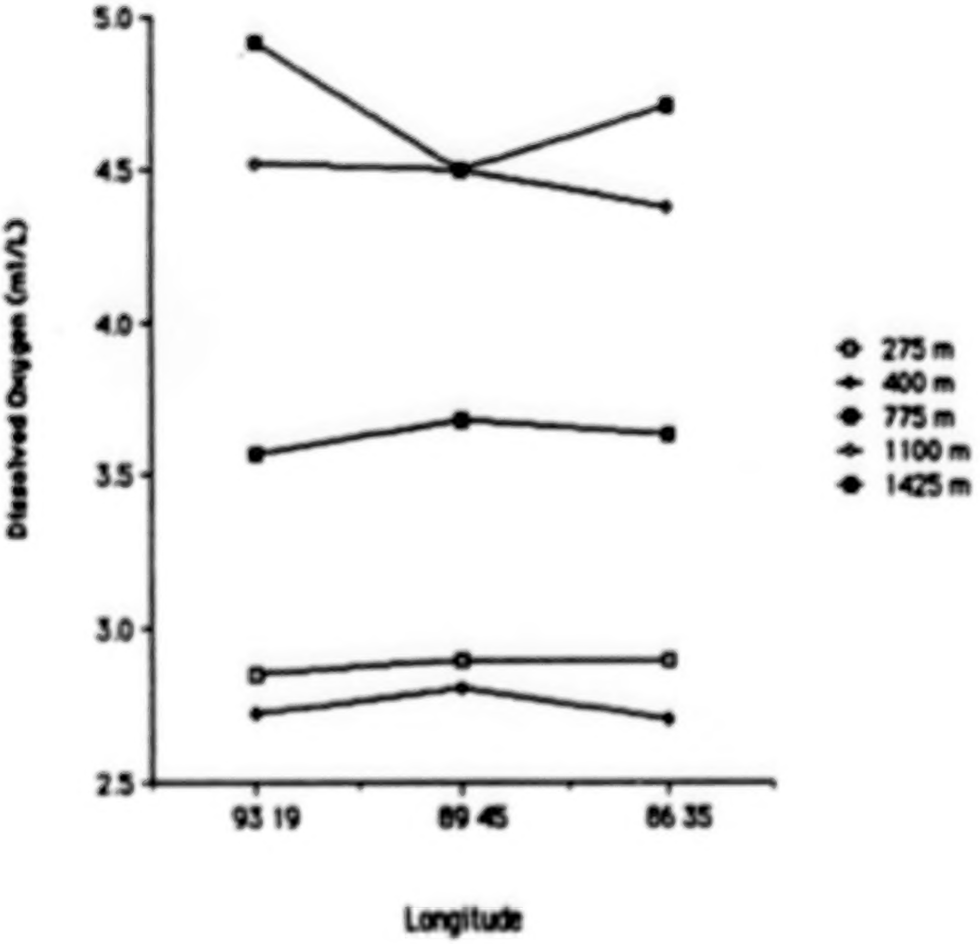

Figure 16. Variation in dissolved oxygen at selected depths measured at 3 stations (W4, C4, E4) across the Gulf during Cruise II.

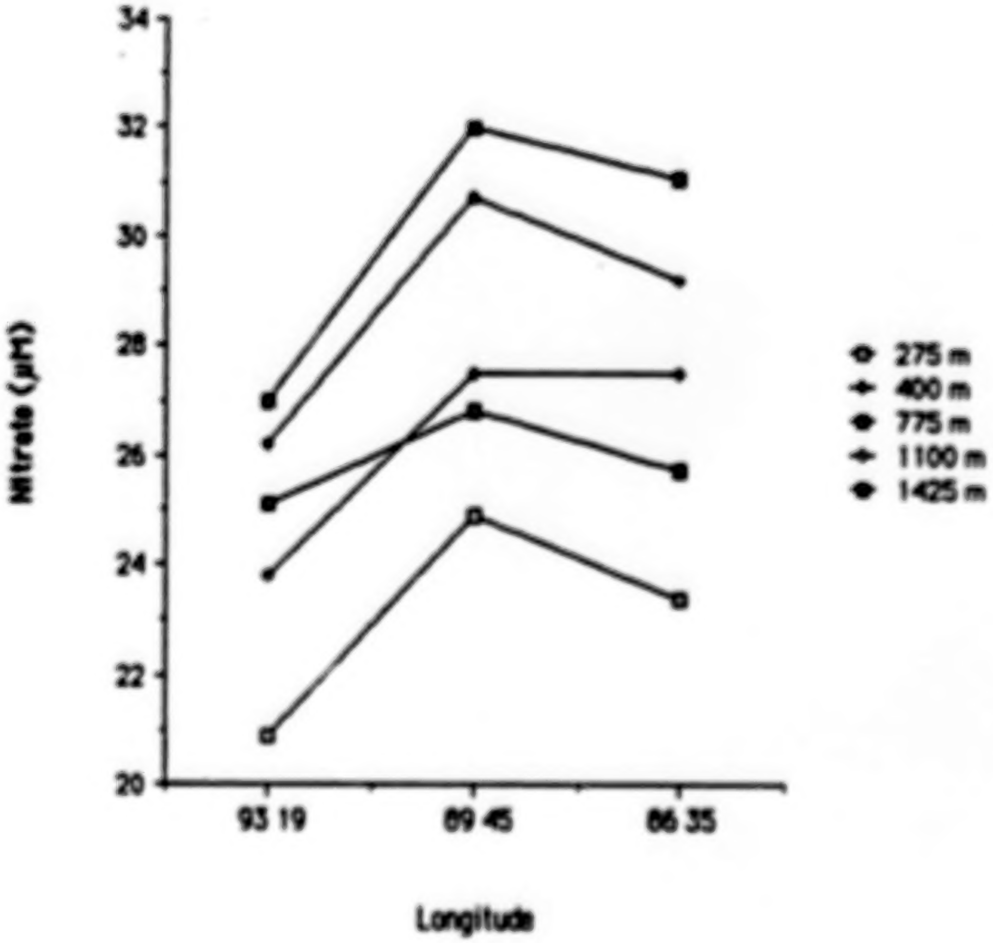

Figure 17. Variation in nitrate at selected depths measured at 3 stations (W4, C4, E4) across the Gulf during Cruise II.

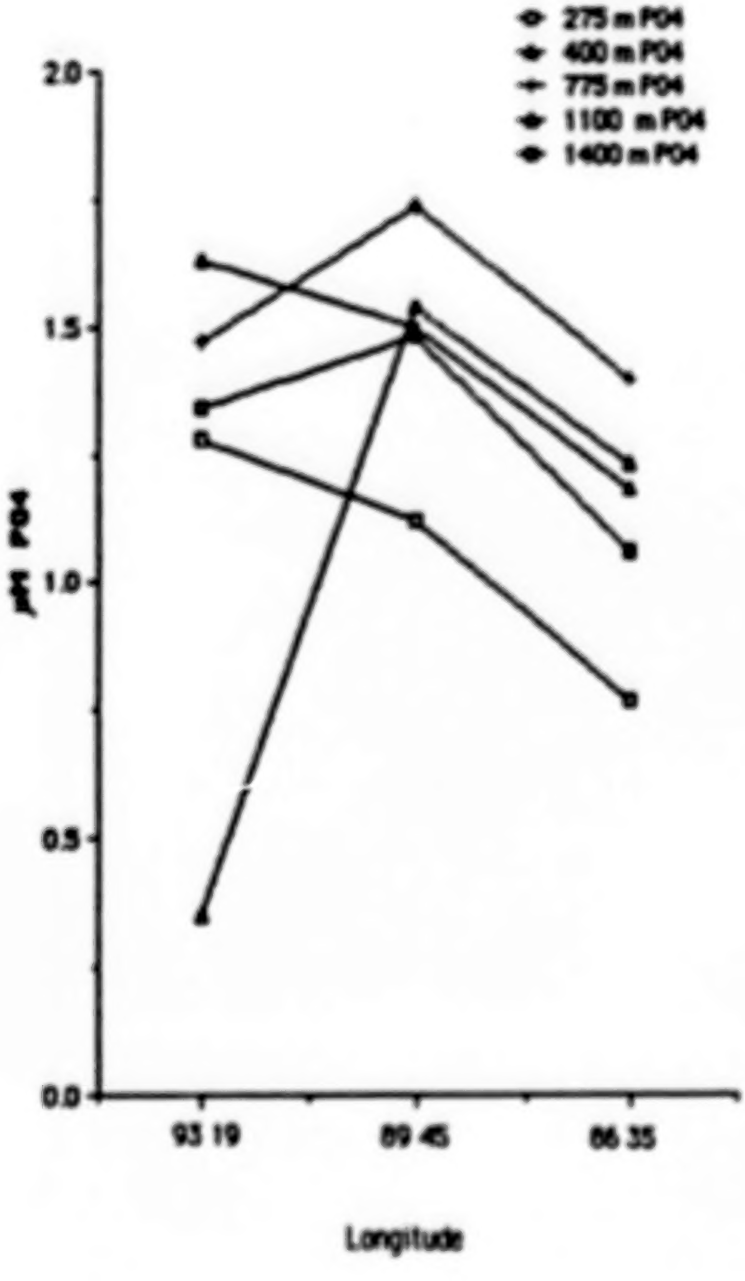

Figure 18. Variation in phosphate at selected depths measured at 3 stations (W4, C4, E4) across the Gulf during Cruise II.

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Silicate concentrations showed less variability at a given depth than either phosphate or nitrate (Fig. 13). Silicate levels increased from near zero values at the surface to maximum values of about 25 to 30 μM at ~800-1000 m. From these depths to the bottom, values decreased on the order of 1-5 μM down to ~ 3000 m. Values were less variable with increased depth.

3.1.5 PARTICULATE ORGANIC CARBON (POC)

POC values ranged from 1 to 83 μgC/l. Many of the higher values were observed at depths of less than 100 m with a tendency for lower levels to be associated with increased depth. However, levels in the 30-45 μgC/l range were observed across 500-2500 m depths. A general decrease from west to east was observed in POC values during Cruise II (Fig. 19).

3.1.6 DISSOLVED ORGANIC CARBON (DOC)

Dissolved organic carbon concentrations, measured on Cruises II, III, and V, decreased with depth. In the top 100 m, values usually were greater than 1.0 mgC/l--at times reaching 2.85 mgC/l. Below 100 m, levels were usually from 0.5 to 0.9 mgC/l although the maximum value observed was 2.85 at 299 m (Cruise III, Station C3).

3.2 SEDIMENTS

3.2.1 SEDIMENT CLASSIFICATION

Sediments were classified into categories using the graphical sediment triangle representing percentages of sand, silt and clay in the sample. Forty-five stations were sampled during a total of five cruises. Five of these stations (C1-C5) were occupied three times and four (E1-E3, E5) were occupied twice. This resulted in a total of 59 station measurements with replicated sediment measurements.

As summarized in Figure 20, the most common (over 55% of the stations) sediment type was silty-clay found in all areas of the Gulf. There were small amounts of variation of the ratios of sand:silt:clay

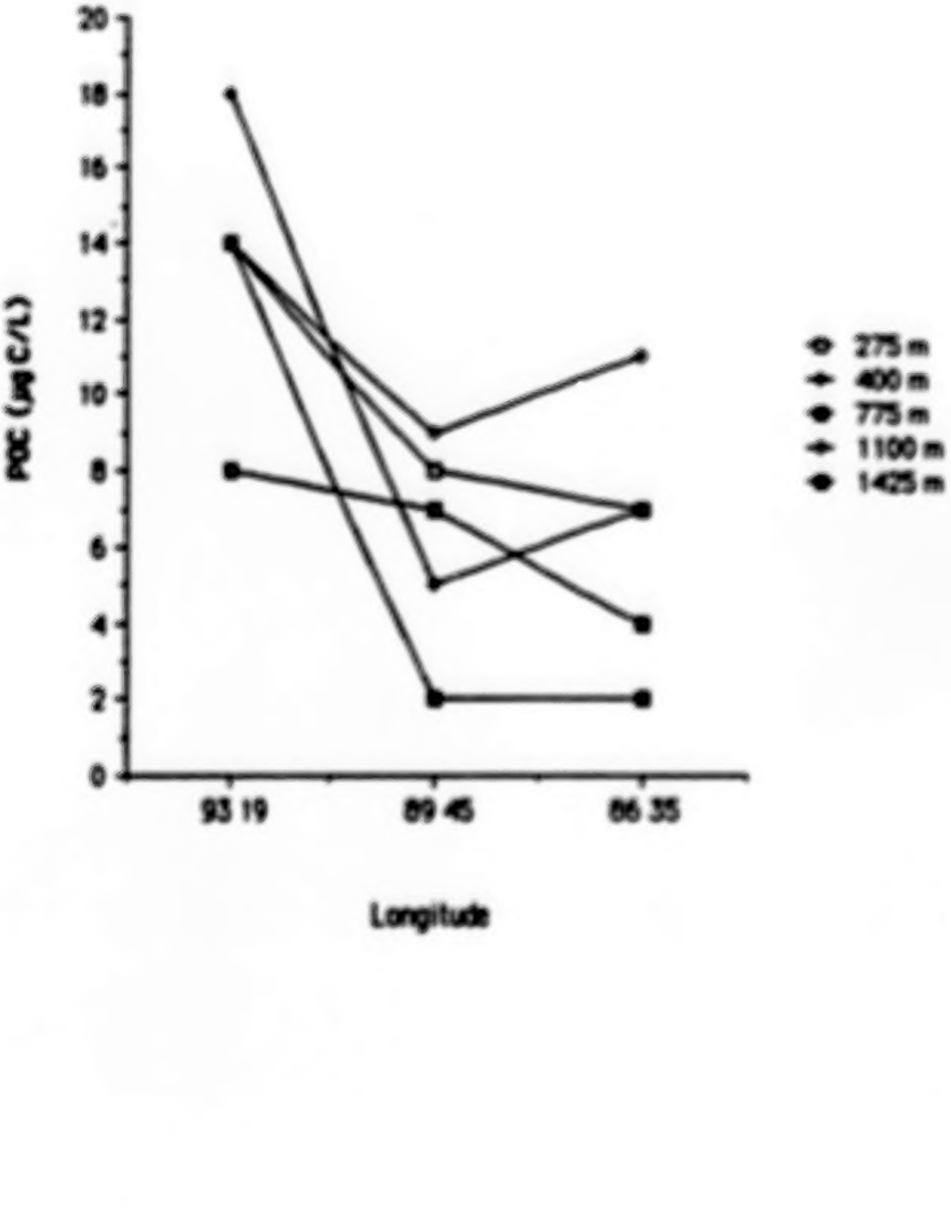


Figure 19. Variation in particulate organic carbon at selected depths measured at 3 stations (W4, C4, E4) across the Gulf during Cruise II.

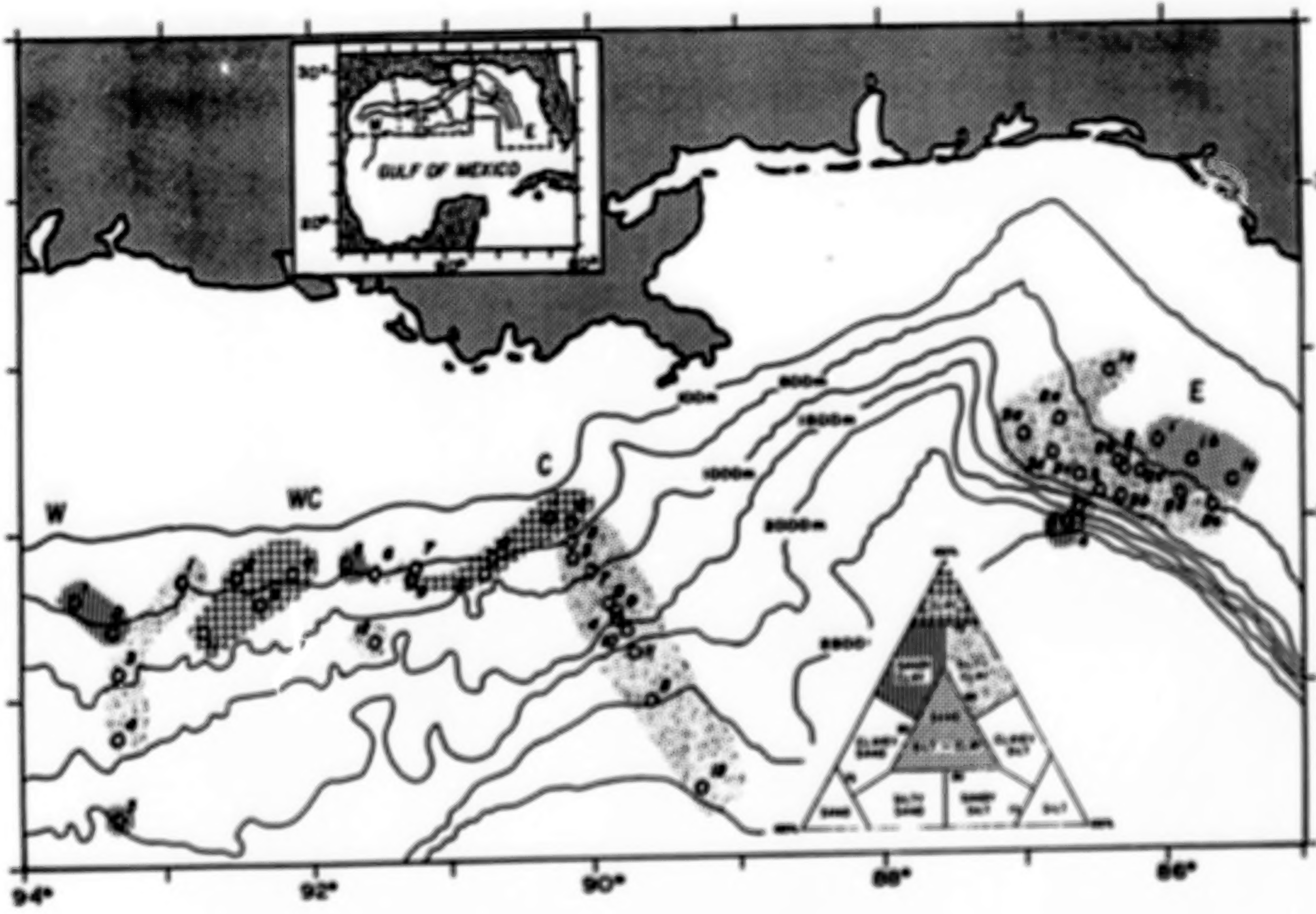


Figure 20. Sediment map.

within this type, depending on the areas of the Gulf sampled. In the eastern Gulf this type had slightly higher percentages of sand than in the western or central areas. Along the Central Transect, there were slightly higher percentages of silt than clay at the deeper stations (C5 and C12).

The second most common sediment type was clay, represented by nine stations in the western and central Gulf at relatively shallow stations (<1226 m). Stations with clay sediments were relatively uniform--i.e., with little variation in the sand-silt-clay proportions.

Sandy clay was observed in the western Gulf at Stations W1, W2, W5 on Cruise II; at WC5 on Cruise V; and in the eastern Gulf at Station E5 on Cruise II. At Station E5 on Cruise IV, the sediment was predominantly clay with approximately equal mixtures of sand and silt, compared to the Western Transect station which had sand in higher proportions than silt.

The sediment type "sand-silt-clay" has approximately equal proportions of each sediment size fraction. Sand-silt-clay sediment was found in the eastern Gulf at Stations E1, E1b, E1c and E2d (at these shallow stations clay was the most abundant of the three parameters and sand was the smallest fraction) and at E4 where clay was the largest fraction but the sand proportion was higher than silt.

Station WC-6 (Cruise V) was difficult to characterize because of the variation among the six replicates. Silty clay is probably the best classification based on average values.

3.2.2 SEDIMENT HYDROCARBONS

Sediments on the Gulf of Mexico continental slope contain a mixture of terrestrial, petrogenic and planktonic-sourced hydrocarbons. The molecular-level alkane distribution was similar in all samples, but the quantitative importance of the three major sources varied with location, time of sampling, and depth. Hydrocarbon concentrations were relatively uniform across the slope, given the large geographical area studied.

Concentrations (ug/gm dry weight of sediment) ranged from 4.0 to 94.2 for extractable organic matter, from 0.1 to 5.2 for the aliphatic hydrocarbons, and from 0.7 to 81.4 for the aliphatic unresolved-complex-mixture (Table 1). A comparison with previous studies showed that these concentrations were generally lower than reported values for Gulf of

Mexico sediments. However, the baseline values were primarily for coastal and shelf sediments.

Individual hydrocarbon compounds were detected at concentrations of <0.01 to >0.5 μg/gm. In general, the qualitative molecular-level alkane distribution was similar at all sites sampled. The dominant normal alkane between n-C_{15} and n-C_{22} was variable, whereas between n-C_{23} and n-C_{32} the dominant n-alkanes were consistently n-C_{29} or n-C_{31}. The alkane distribution in samples from the Central Transect during Cruise I are typical of all locations sampled (Fig. 21). Detailed sediment hydrocarbon data for each station are found in Appendices B-4, B-5, and B-6.

3.2.2.1 Hydrocarbon Sources--The Approach

Molecular-level and bulk parameters can be used to estimate the relative importance of hydrocarbon sources at a given location. These parameters are based on the premise that a hydrocarbon source has a unique "fingerprint", i.e., a recognizable suite of compounds. In nature, however, few unique end-members occur. Several diagnostic indicators were monitored to better understand the dynamics of hydrocabons in Gulf of Mexico slope sediments (see Table 1).

Table 1. Suggested molecular-level indicators of specific hydrocarbon sources to sediments on the Gulf of Mexico continental slope.

Indicator Compound	Source	Abbreviation
n-$C_{15,17,19}$ and Pristane	Planktonic/Petroleum	PL-1
n-$C_{16,18,20}$ and Phytane	Petroleum/(Planktonic?)	PE-Lo
n-$C_{25,27,29,31}$	Land/(Petroleum)	TERR
n-$C_{24,26,28,30}$	Petroleum/(Biogenic)	PE-Hi
Unresolved-Complex-Mixture	Petroleum/(Biogenic?)	UCM

Certain assumptions need to be understood in order to properly evaluate these distributions as indicators of hydrocarbon sources. Plankton generally produce a simple mixture of hydrocarbons, including

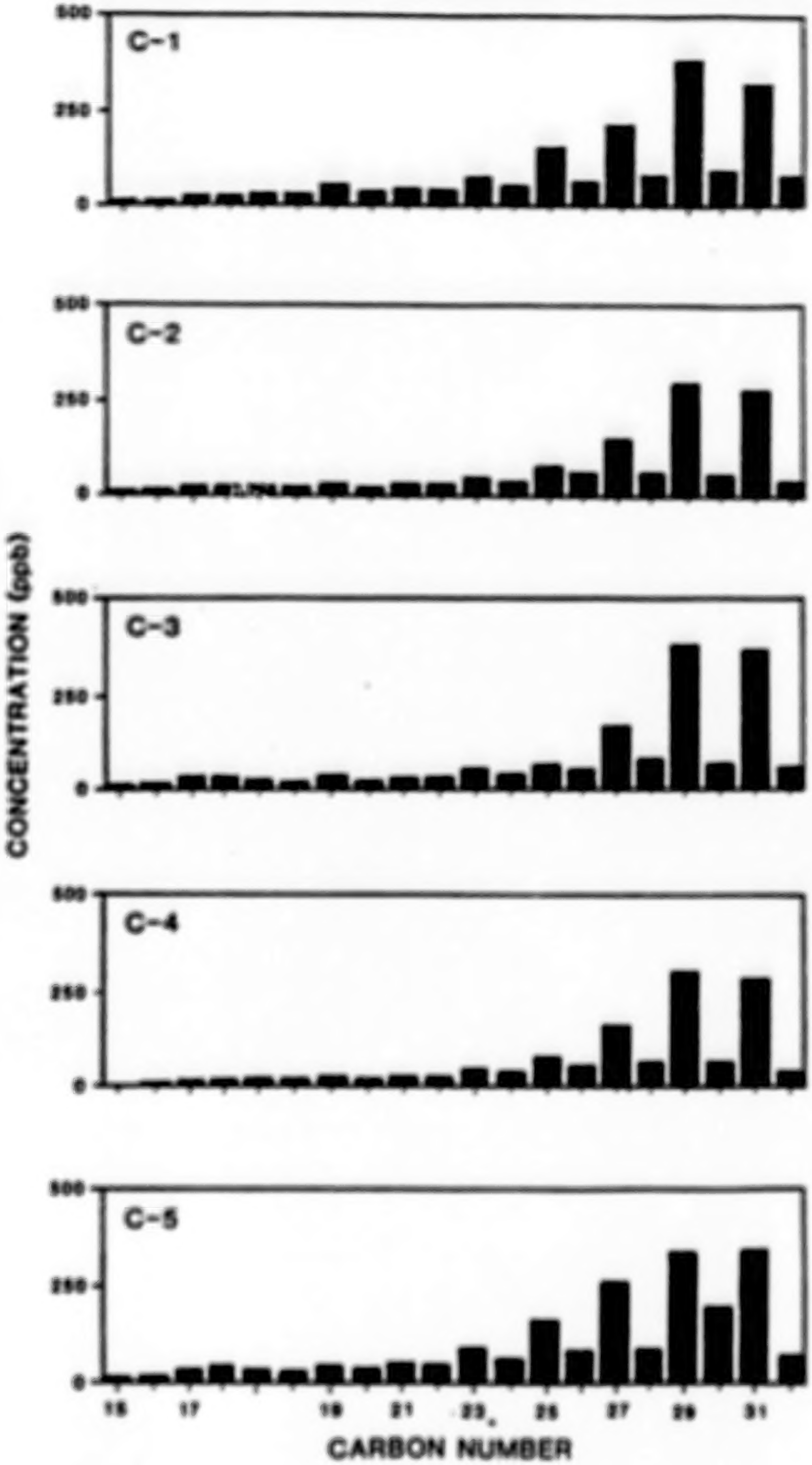


Figure 21. Molecular level alkane distributions for sediments from the central transect during Cruise I (ng/gm dry wet of sediment,ppb).

n-C_{15}, n-C_{17}, n-C_{19} and pristane, so the presence of these compounds can indicate a planktonic hydrocarbon source (PL-1). Petroleum also contains these compounds, but usually also contains comparable amounts of the alkanes n-C_{16}, n-C_{18}, n-C_{20}, and phytane as well. Thus a low molecular weight petroleum indicator (PE-Lo) can be used to assess the petroleum component of the planktonic indicator. To make this calculation we assume that the contribution of petroleum to each indicator is equal; therefore the planktonic component can be inferred as the diffference between PL-1 and PE-Lo. Straight chain biowaxes with n-C_{25}, n-C_{27}, n-C_{29}, and n-C_{31} alkanes have been used extensively as an indicator of terrestrial or land-derived input. As such, the sum of these four normal alkanes can be used to indicate the terrestrial (TERR) hydrocarbon component. As with the planktonic indicator, these normal alkanes can also have a source in petroleum. Again, in general, petroleum also contains a near equal amount of the even alkanes n-C_{24}, n-C_{26}, n-C_{28}, and n-C_{30} (PE-Hi). As in the planktonic indicator, the terrestrial component can be estimated by subtracting the PE-Hi from the TERR concentration. Plants themselves can also contain significant amounts of indigenous even carbon alkanes; thus this type of indicator provides a measure of maximum petroleum contribution and a minimum terrestrial contribution over this molecular weight range. In summary the planktonic input is estimated as [(PL-1)-(PE-Lo)], the terrestrial input as [TERR)-(PE-Hi)], and the petroleum input as [(PE-Lo)+(PE-Hi)]. These parameters are used to assess hydrocarbon inputs and not bulk organic matter since hydrocarbons represent only a small fraction of the total organic carbon present in a sediment.

These parameters, with the above mentioned limitations, can be used to study the hydrocarbon dynamics on the continental slope as a function of water depth, location, and time of sampling. Also included is the evaluation of parameters such as the unresolved-complex-mixture (UCM), an indicator of petroleum input; the carbon preference index (CPI), an indicator of the relative amounts of odd and even normal alkanes; and bulk sediment characteristics.

3.2.2.2 Areal Distribution

Cruise II assessed the distribution of sediment hydrocarbons on transects from the central, western, and eastern Gulf of Mexico continental slope. Extractable organic matter (EOM) is a composite of biogenic and petroleum related material. Extractable organic matter concentrations were generally lowest on the Eastern Transect and nearly equal on the Western and Central Transects, with the exception of Station W1 (Fig. 22). The aliphatic unresolved-complex-mixture (UCM), a petroleum indicator, was similar over all three transects though slightly elevated in Western Transect sediments (see Table 1). The elevated EOM at Station W1 was due to an increased UCM i.e., petroleum component.

The amount of terrestrial hydrocarbons decreased from the Central to the Western to the Eastern Transect (Figs. 23 and 24). Terrestrial hydrocarbon concentrations, as indicated by the sum of n-C_{25}, n-C_{27}, n-C_{29}, and n-C_{31} (TERR) concentrations, were relatively uniform with water depth on the Central and Western Transects; whereas terrestrial hydrocarbons increased with water depth on the Eastern Transect. The influence of the land- and/or river-derived material was readily apparent in all three regions and accounts for a majority of the GC-resolvable alkanes.

In general, planktonic inputs accounted for less than 10% of the GC-resolvable alkanes. Sediment biogenic hydrocarbons on the slope were dominated by the more resistant terrestrial components and the degree of dominance was a function of proximity to the Mississippi River and delta. The steepness of the slope and the prevailing currents affect the observed distributions as well. Planktonic inputs were low and often difficult to discern on the Central and Western Transects (Figs. 23 and 24). The planktonic input was generally higher at the shallower stations of these two transects. The low planktonic hydrocarbon concentrations on the Central and Western Transects may be due to a high sedimentation rate and/or dilution with riverine material. On the Eastern Transect the planktonic input was discernible and relatively constant with depth.

Petroleum inputs, measured both by alkane parameters and the unresolved-complex-mixture, were detected at all sites (Figs. 23 and 24). In general, petroleum input was greatest on the Central Transect, with

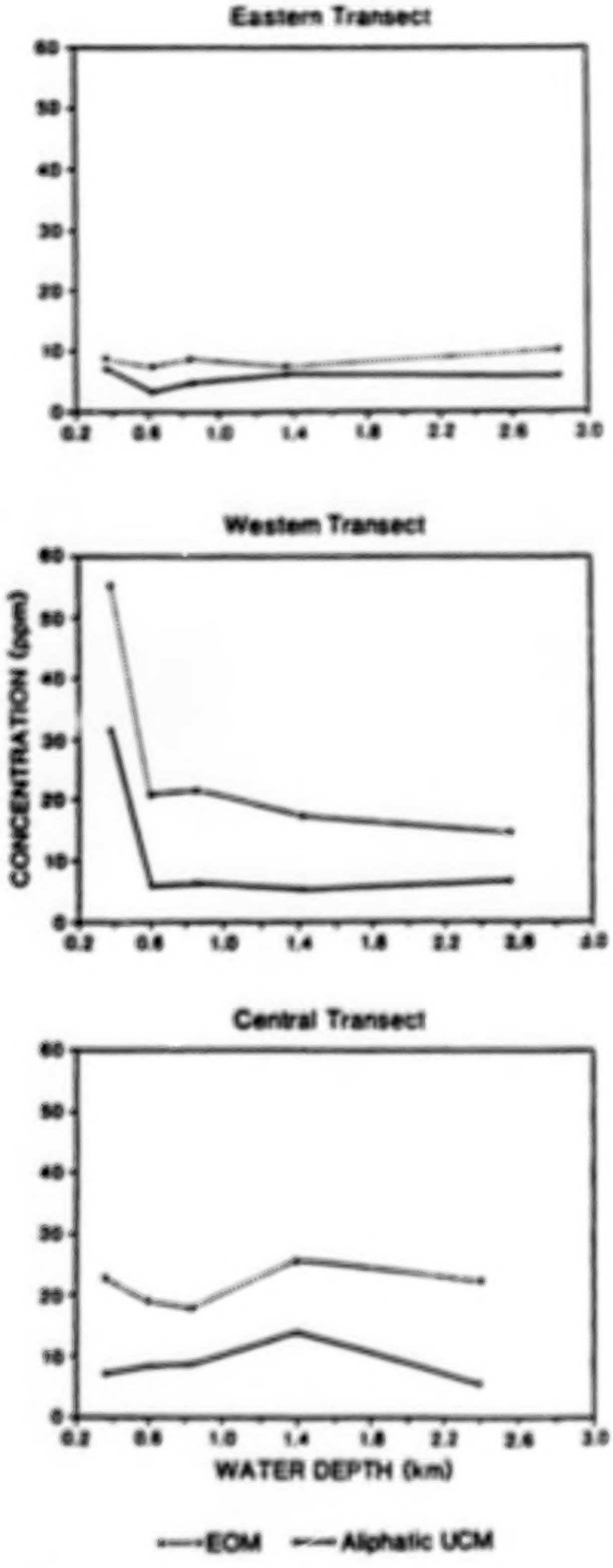


Figure 22. Variation in extractable organic matter (EOM) and the aliphatic unresolved complex mixture (UCM) along transects in the eastern, western, and central Gulf of Mexico continental slope.

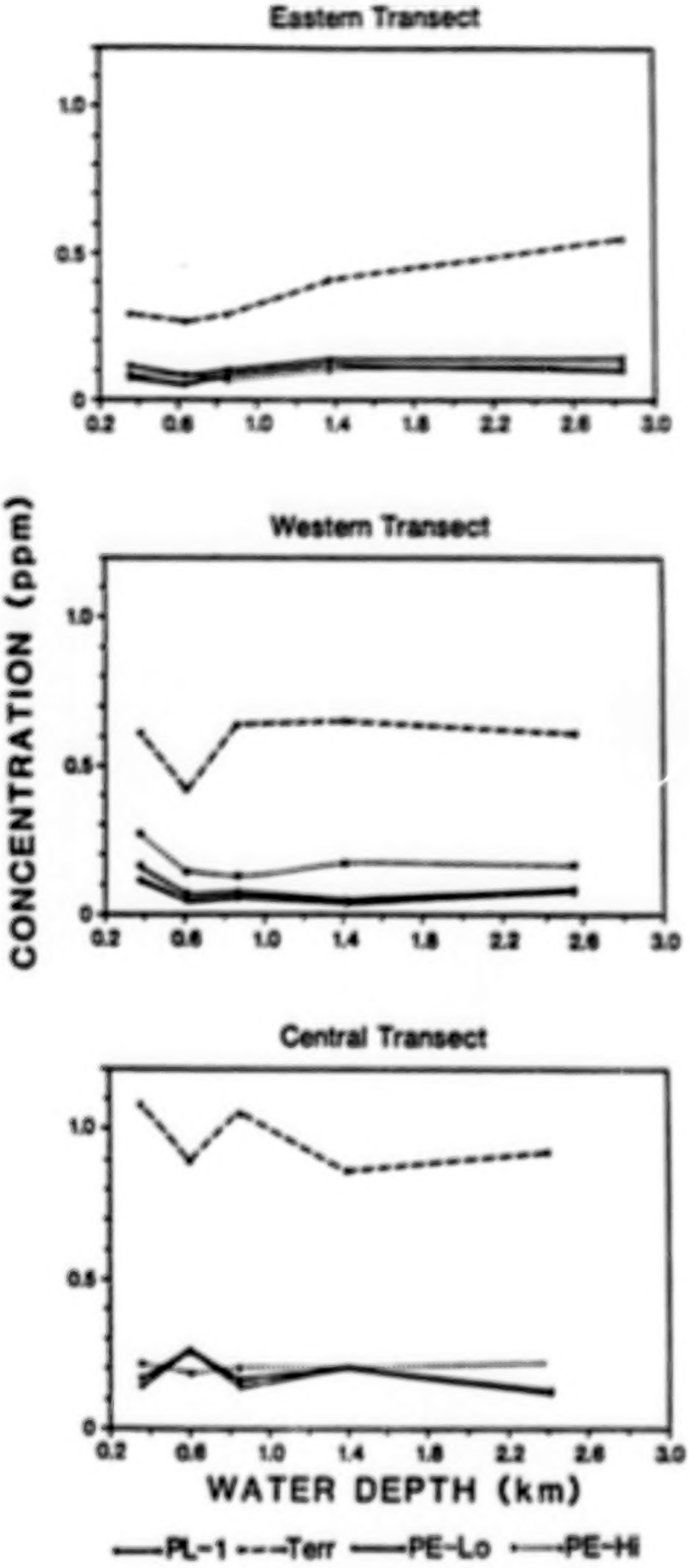


Figure 23. Variation in hydrocarbon source parameters along transects in the eastern, western, and central Gulf of Mexico continental slope.

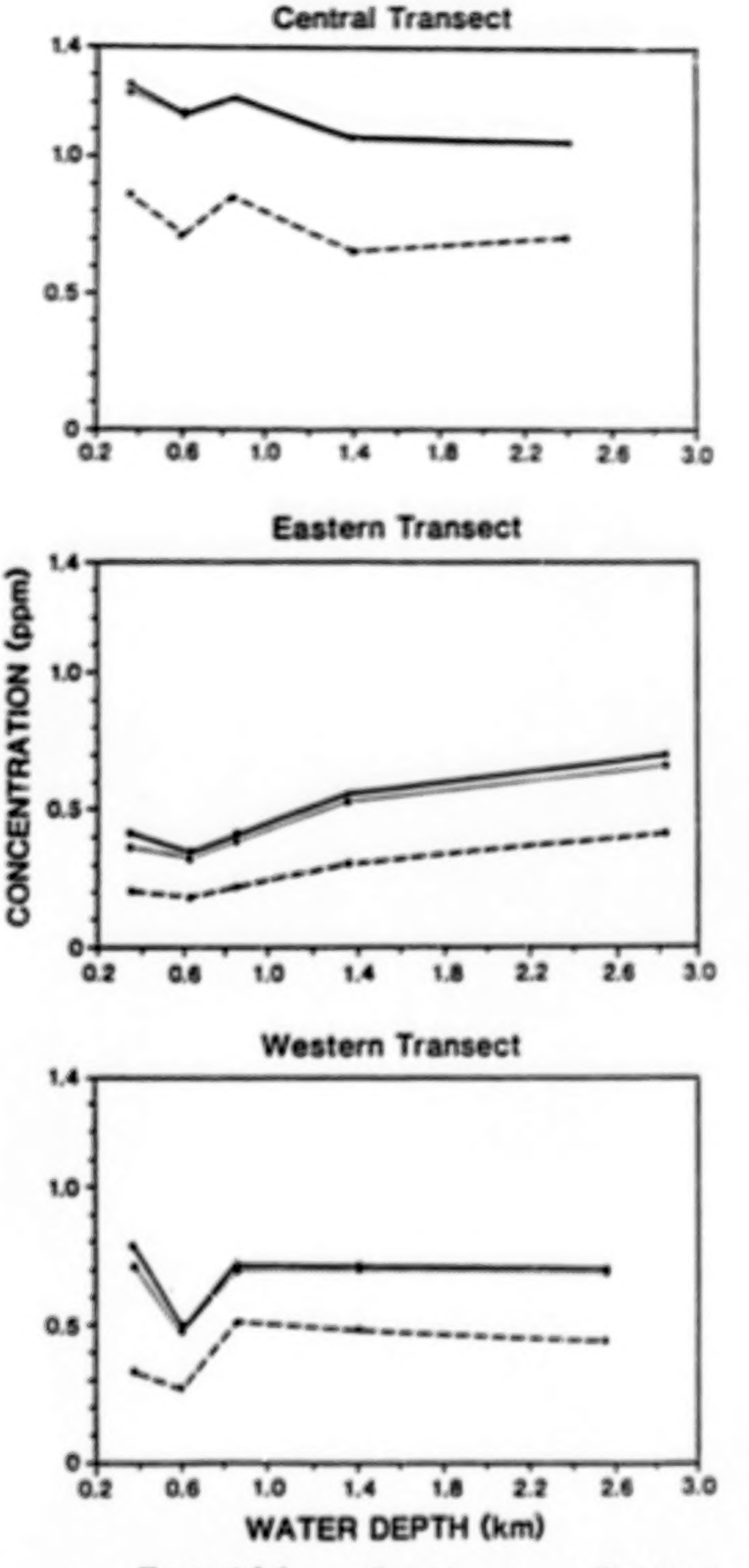


Figure 24. Variation in planktonic, terrestrial, and petroleum hydrocarbons along three transects presented as a cumulative concentration (i.e., the first concentration plotted is terrestrially sourced hydrocarbons, second is terrestrial + petroleum, and third is terrestrial + petroleum + planktonic).
]

lesser amounts at the Western and Eastern Transects. The maximum estimate of petroleum-sourced hydrocarbons indicates relatively low concentrations at all locations. To determine if the petroleum hydrocarbons detected were due to transported terrestrial particles (most likely by mass movement and turbidity flows after initial deposition near the river's mouth) or to upward migration from deeper reservoired petroleum, the petroleum indicators were compared with the terrestrial and planktonic indicators (Fig. 25). These comparisons suggest a dual source for the sediment petroleum hydrocarbons. Low molecular weight hydrocarbons (PE-Lo) correlate with a terrestrial input on the Eastern Transect, but not on the Central and Western Transects. The higher molecular weight petroleum indicator (PE-Hi) also correlates with the terrestrial indicator (TERR) on the East but not on the other transects. An estimate of the amount of petroleum hydrocarbons is provided by the UCM. The UCM was generally independent of the planktonic or terrestrial input (Fig. 26) which suggests an additional source of hydrocarbons (such as upward migration from deeper reservoirs) on the Central and Western Transects. An anomaly was seen at Station W1, which contains petroleum hydrocarbon concentrations that were significantly elevated in comparison with other Western Transect stations.

This attempt to correlate petroleum and terrestrial sediment inputs assumes that the ratio of petroleum to terrestrial hydrocarbons transported to a location is constant with time, which may or may not be true. However, extensive natural hydrocarbon seepage has been documented on the Gulf of Mexico continental slope, further supporting natural seepage as a major petroleum hydrocarbon input to Gulf of Mexico continental slope sediments. It is also evident that some fraction of the petroleum hydrocarbons are transported to the slope by river/land-derived particles most likely by secondary movement such as slumps and/or turbidity flows.

3.2.2.3 Temporal Variations

Cruises I (November 1983), II (April 1984), and III (November 1984) sampled the Central Transect in an attempt to document variability between samplings. The distribution of EOM and aliphatic UCM during these three

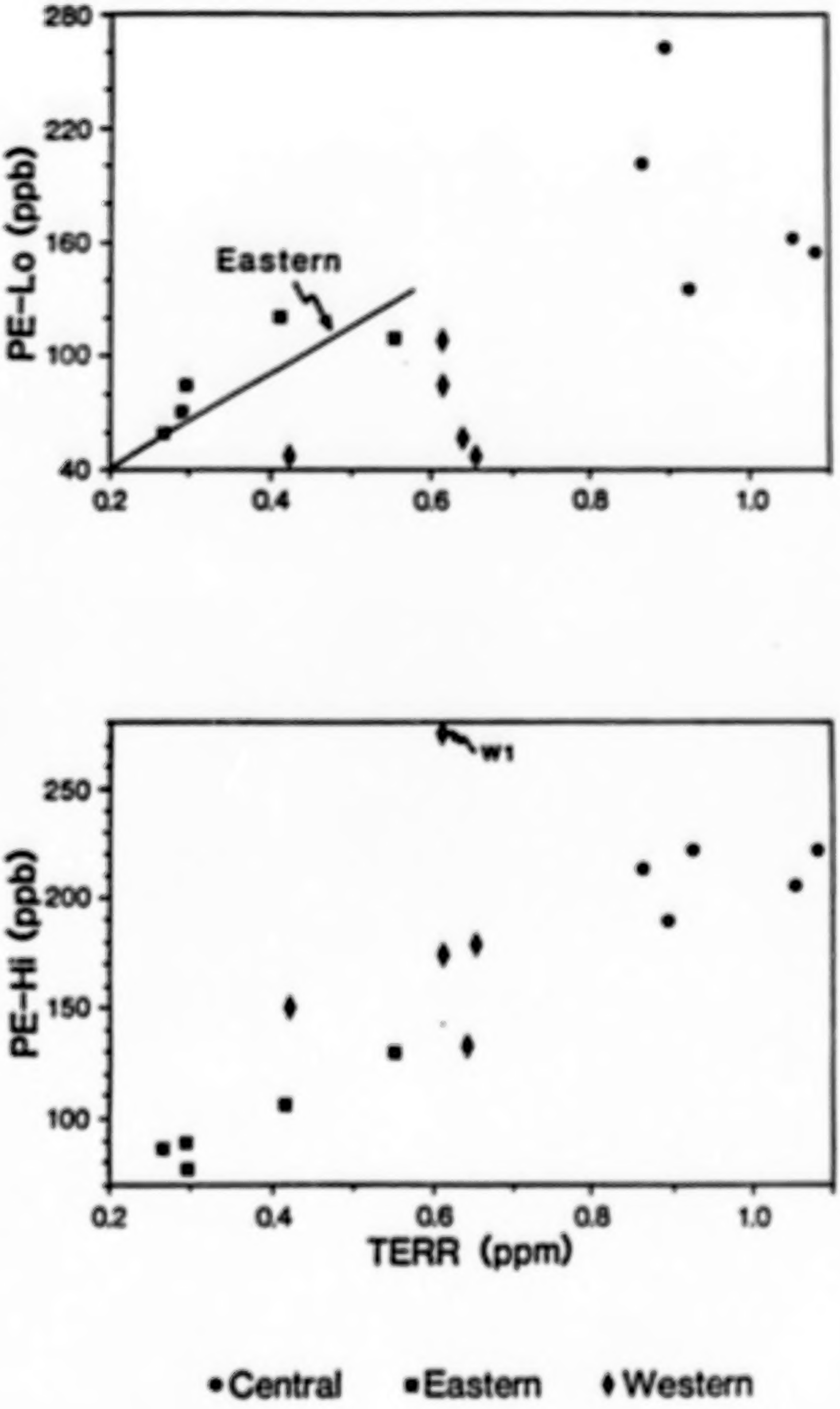


Figure 25. The relationship between alkane petroleum indicators and a terrestrial indicator.

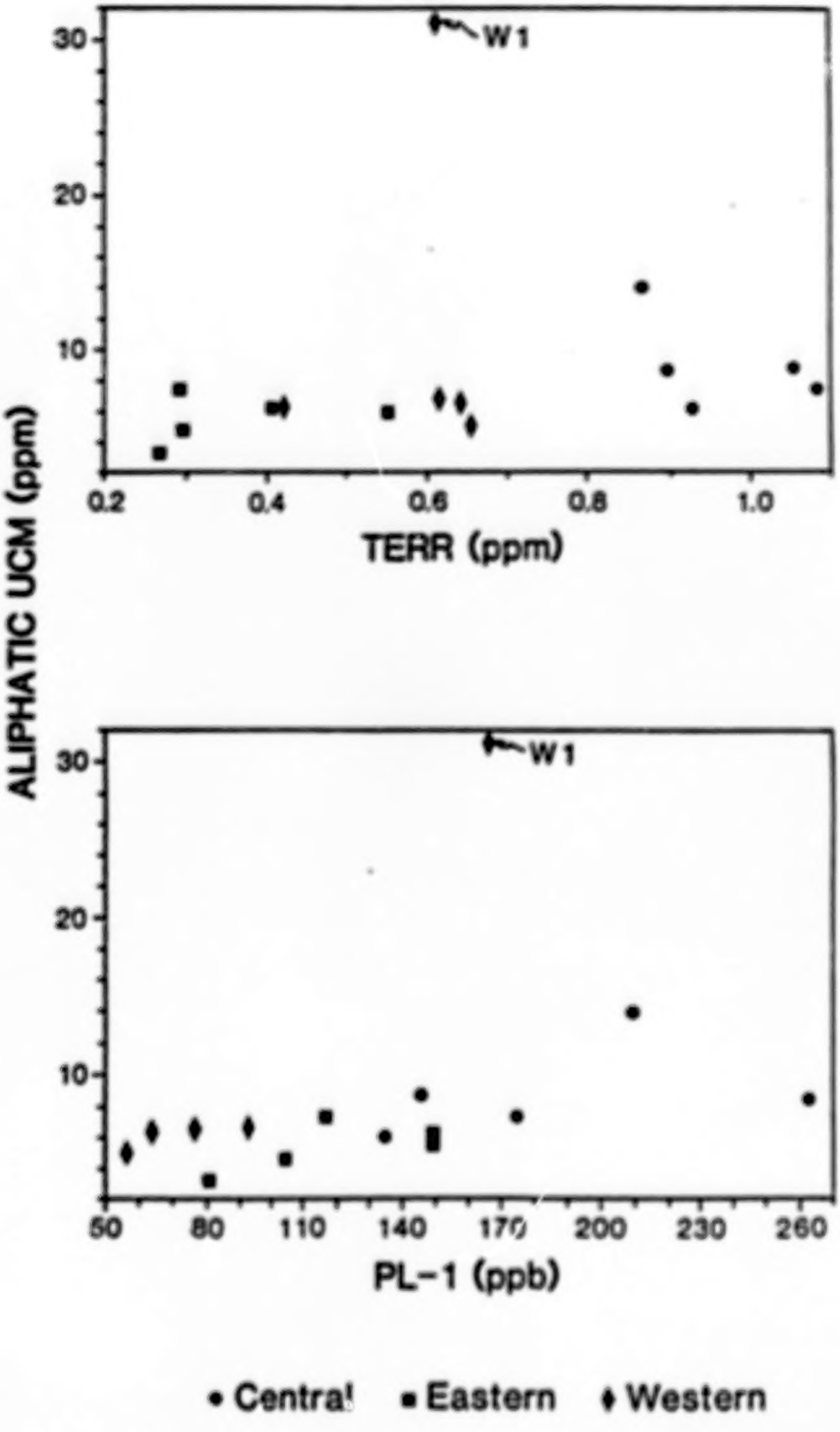


Figure 26. The relationship between the aliphatic unresolved complex mixture (a petroleum indicator) and the planktonic and terrestrial alkane indicator.

sampling cruises is shown in Figure 28. On an average, the aliphatic UCM, a petrogenic indicator, was highest on Cruise I (Fig. 27, Table 1). UCM concentrations during Cruise II and at the shallower stations (<1500 m) of Cruise III, were similar. During Cruise III the UCM was markedly higher at stations deeper than 1500 m than had been observed on Cruises I and II. Molecular-level indicators were similar along the Central Transect during Cruises I and II (Figs. 28 and 29), but substantial differences were also observed on Cruise III at depths greater than 1500 m.

Significant variability with depth was observed during Cruise III sampling. Shallower stations (<1500 m) during Cruise III were lower in hydrocarbons than the two previous samplings, which suggests dilution by inorganic material. Compared with Cruises I and II, terrestrial hydrocarbons were significantly reduced over the entire transect. The deepest stations (>1500 m) on Cruise III had elevated levels of petroleum hydrocarbons. This is substantiated by the hydrocarbon-source parameters previously discussed (Figs. 28 and 29). Examination of carbon preference index (PI) distributions and gas chromatograms suggest the presence of relatively fresh petroleum hydrocarbons, probably from oil seepage, at the deepest stations (Fig. 30). Station C7 also had a low CPI, suggesting anomalously high petroleum hydrocarbons. These differences between samplings most likely represent the patchiness of hydrocarbon distributions rather than a temporal change such as an influx of hydrocarbons. Station C7 was later documented to have oil seep-community organisms in residence.

3.2.2.4 Variability Along Isobaths

Cruise V in the eastern Gulf of Mexico occupied stations along three isobaths to assess lateral variation in the measured parameters. Hydrocarbon parameters are summarized in Table 2. Bulk and molecular-level hydrocarbon parameters were low during this sampling and represent some of the lowest values measured during this study (Table 1). Therefore, the variability observed along this transect is most likely a maximum. Cruise V sampling sites were also chosen to contrast sediment texture which will also contributes to the high degree of variability of hydrocarbon parameters observed. The aliphatic UCM and total EOM varied

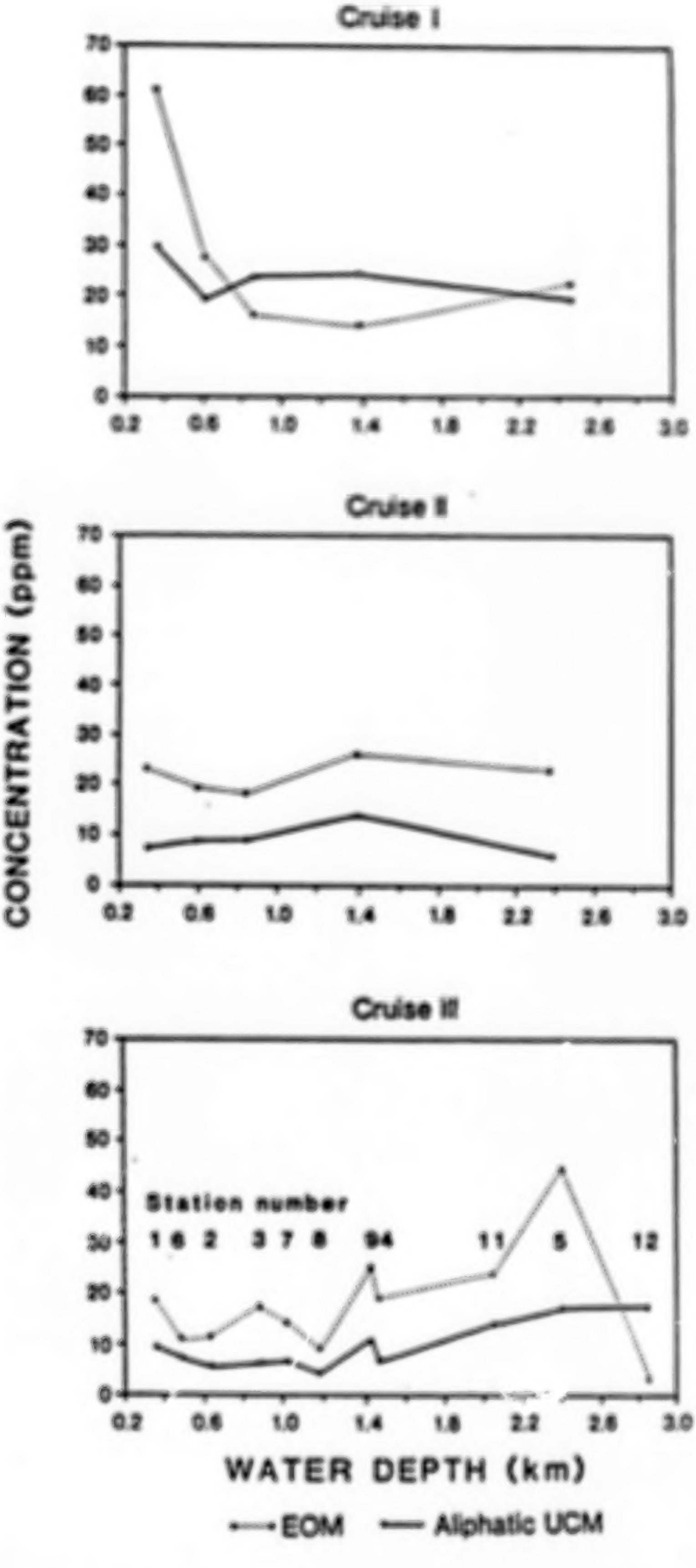


Figure 27. Variations in extractable organic matter (EOM) and the aliphatic unresolved complex mixture (UCM) during 3 samplings of the central transect.

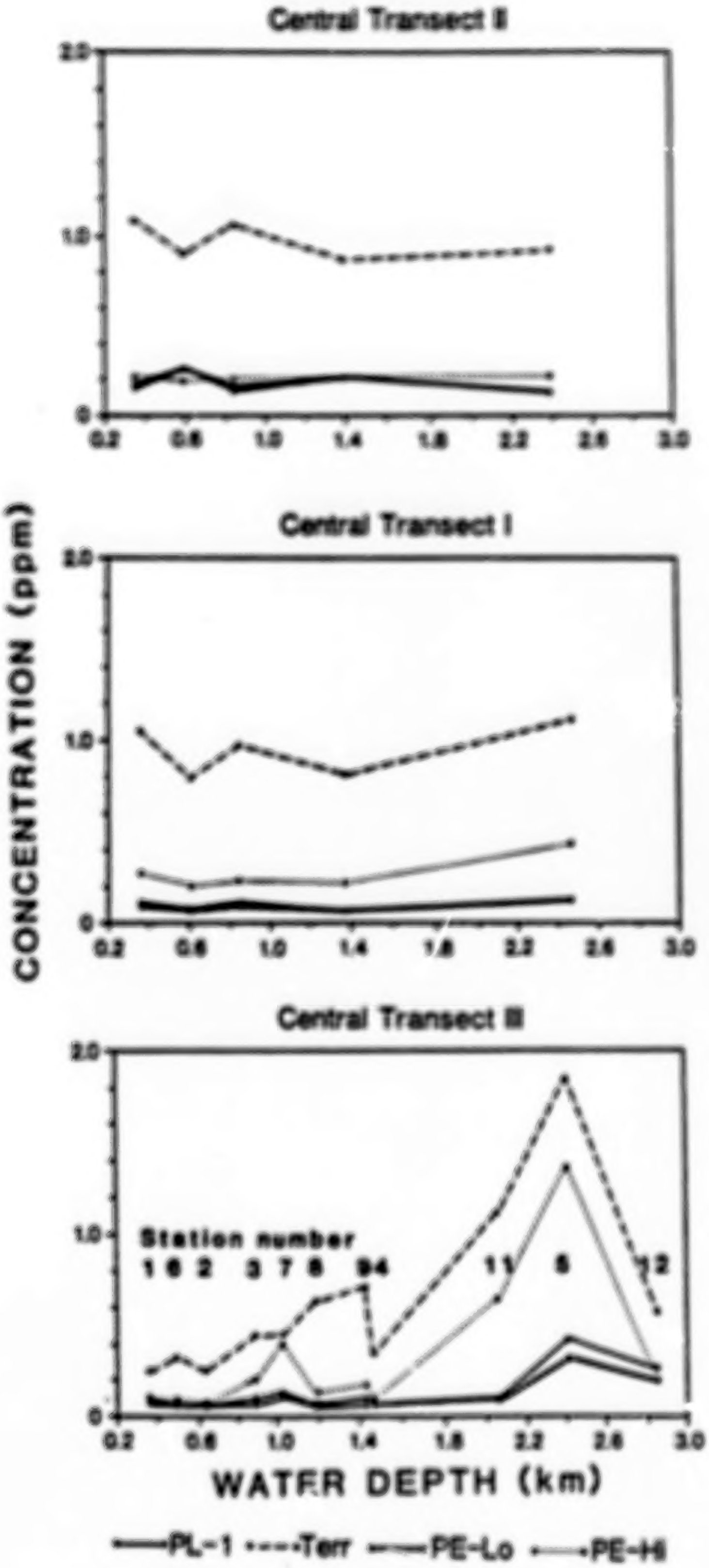


Figure 28. Variations in hydrocarbon source paramaters during three samplings of the central transect.

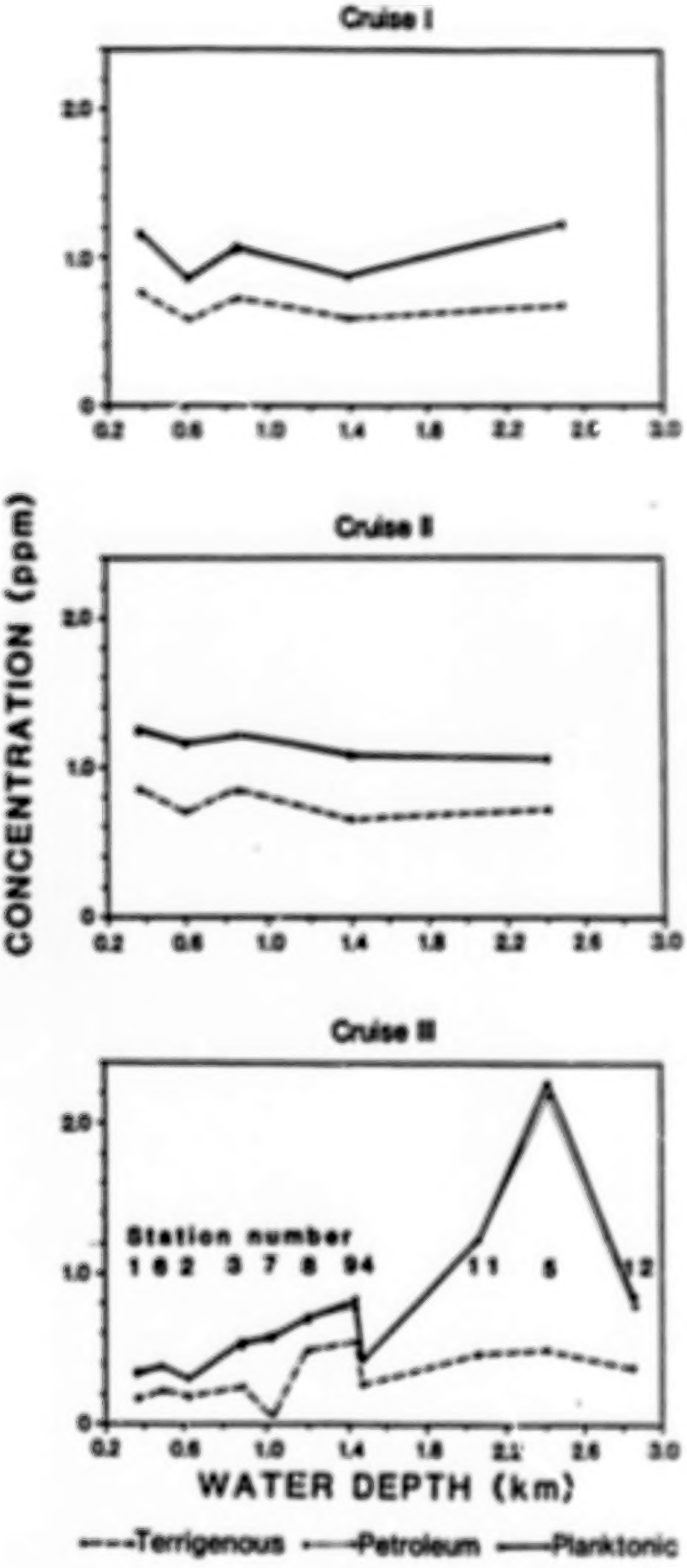
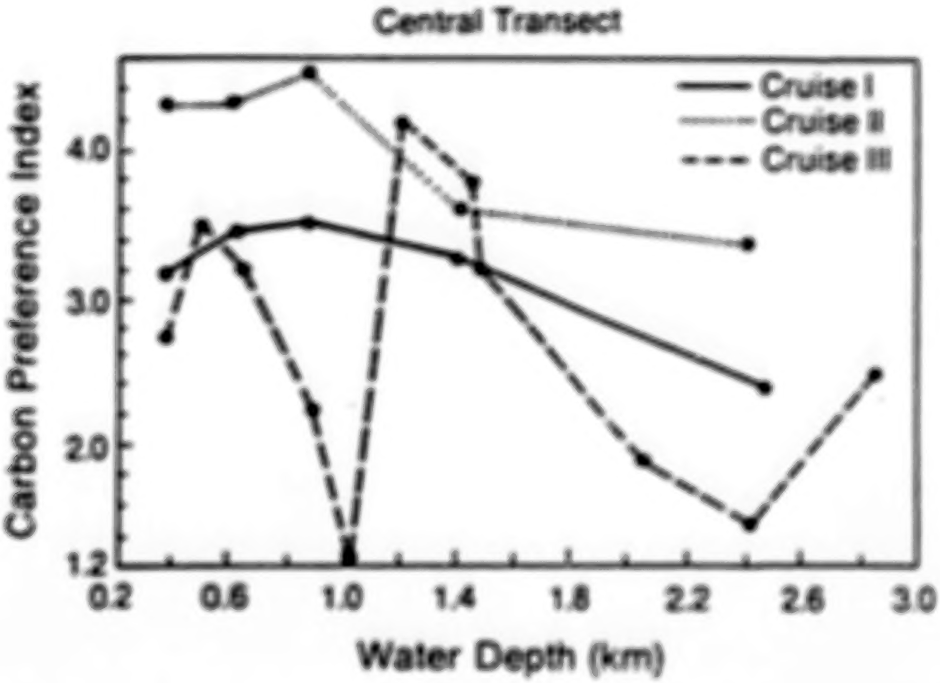


Figure 29. Variation in plankton, terrestrial and petroleum hydrocarbons during three samplings of the central transect presented as a cumulative concentration.



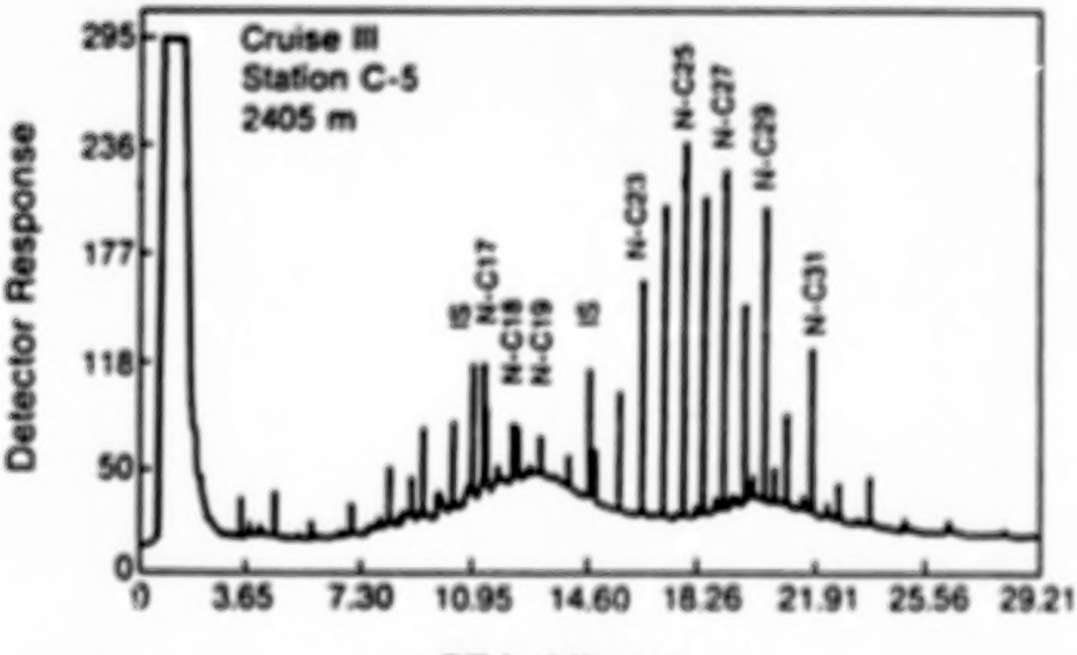


Figure 30. Variation in the carbon preference index (CPI) as a function of depth along the Central Transect during Cruise III and a representative fused silica gas chromatogram of the aliphatic hydrocarbons from Station C5, Cruise III (CPI = $[\Sigma n\text{-}C_{23+25+27+29+31}] / [\Sigma n\text{-}C_{24+26+28+30+32}]$).

Table 2. Variability in hydrocarbon parameters along isobaths - eastern Gulf of Mexico.

Depth (m) Parameter	Variable Ranges 342-383 n=4	619-630 n=6	819-859 n=5
Total EOM (ppm)	5.8 - 13.4 (9.7)[1]	4.7 - 9.9 (6.8)	4.9 - 8.2 (5.8)
Aliphatic (ppm)	0.7 - 5.0 (3.0)	0.5 - 3.8 (1.8)	0.7 - 3.1 (1.7)
PL-1[2] (ppb)	11.5 - 94.1 (54.3)	8.1 - 59.1 (29.9)	6.9 - 44.8 (23.4)
TERR[2] (ppb)	36.0 - 74.0 (55.9)	55.9 - 119.8 (78.6)	23.4 - 147.5 (121.6)
PE-Lo[2] (ppb)	13.3 - 100.7 (56.2)	13.5 - 39.8 (21.1)	11.0 - 27.3 (18.8)
PE-Hi[2] (ppb)	14.4 - 30.3 (22.3)	20.4 - 53.1 (33.1)	17.5 - 77.6 (48.6)
Terrigenous[3] (ppb)	21.6 - 49.8 (33.6)	24.0 - 66.7 (45.4)	5.9 - 99.5 (72.8)
Petroleum[3] (ppb)	33.5 - 118.3 (78.5)	34.6 - 67.9 (54.3)	28.5 - 103.5 (67.4)
Planktonic[3] (ppb)	0.0 - 2.8 (0.7)	0.0 - 20.1 (9.5)	0.0 - 17.5 (7.3)

[1] Average.

[2] PL-1 = Σn-$C_{15, 17, 19}$ and Pristane; TERR = Σn-$C_{25, 27, 29, 31}$; PE-Lo = Σn-$C_{16, 18, 20}$ and Phytane; PE-Hi = Σn-$C_{24, 26, 28, 30}$.

[3] Terrigenous = (TERR) - (PE-Hi); Petroleum = (PE-Lo + PE-Hi); Planktonic = (PL-1) - (PE-Lo).

by factors of 1.7 to 7.6 at a given depth. Molecular-level indicators (i.e., individual component sums) varied by a factor of 2.0 to 7.6 along a given isobath. This data suggests that, at these low concentrations, hydrocarbons are as variable along isobaths as they are with water depth. This again emphasizes the patchy nature of hydrocarbon distributions. Bulk sediment parameters varied by as much as a factor of 3 along an isobath illustrating the variations observed in sediment texture.

Samples along isobaths in the central and western Gulf were also taken. Stations from Cruises I, II, III and IV at ~350 m are compared in Table 3. The variability in hydrocarbon parameters reflecting terrestrial input show the greatest variation, i.e., as much as 40 fold. The planktonic indicators are also highly variable, most likely due to dilution with terrestrially sourced material. Bulk parameters such as clay content varied by a factor of 2 and sand content varied from 0.5 to 36.6% at these six locations. These variations reflect the substantial influence of river/land derived material. Three samples from Cruise IV along the 550- and 750-m isobath were relatively uniform. The lateral extent covered at these isobaths was small relative to the 350-m isobath sampling. Bulk parameters were also uniform along these two isobaths.

3.2.2.5 Aromatic Hydrocarbons

Sediment aromatic hydrocarbons were below the detection limit (~5 ppb) at all locations sampled. The presence of aromatic hydrocarbons at low concentrations was inferred by total scanning fluorescence analyses, supporting the conclusion that a low level petroleum input was present at all locations sampled.

3.3 CARBON ISOTOPES

3.3.1 SEDIMENTS

The carbon isotopic composition of sedimentary organic matter for all five cruises is summarized in Figure 31. Isotopic data confirms the previously inferred influence of river-borne terregenous material on the Gulf of Mexico continental slope. Though there are numerous complicating

Table 3. Variability in hydrocarbon parameters along isobaths - west/central Gulf of Mexico.

Depth Parameter	298-371[1] n=6	547-550[2] n=3	748-759[3] n=3
Total EOM (ppm)	15.9 - 61.3 (34.5)	17.4 - 23.9 (20.6)	17.0 - 57.9 (30.9)
Aliphatic UCM (ppm)	6.0 - 31.4 (15.6)	6.9 - 7.9 (7.6)	5.6 - 11.9 (8.4)
PL-1 (ppb)	36.3 - 174.9 (121.8)	47.4 - 65.3 (56.4)	50.0 - 68.0 (59.9)
TERR (ppb)	93.4 - 1082.8 (546.7)	109.8 - 273.1 (201.2)	169.7 - 180.5 (176.3)
PE-Lo (ppb)	36.2 - 154.5 (100.3)	39.1 - 52.5 (43.7)	43.4 - 48.9 (45.2)
PE-Hi (ppb)	70.9 - 279.7 (172.2)	80.6 -121.9 (99.4)	48.0 - 96.6 (64.8)
Terrigenous (ppb)	22.5 - 860.6 (374.5)	29.2 - 252.2 (101.7)	83.9 - 130.8 (111.5)
Petroleum (ppb)	123.3 - 388.0 (127.4)	119.7 - 161.5 (143.2)	91.4 - 140.0 (110.1)
Planktonic 9ppb)	0.1 - 57.7 (21.5)	4.0 - 26.2 (12.7)	6.6 - 19.1 (14.7)

---

[1] Cruises I, II and III, Stations E1 and W1; Cruise IV, Stations WC1 and WC2.

[2] Stations WC2, WC4, WC8.

[3] Stations WC3, WC9, WC10.

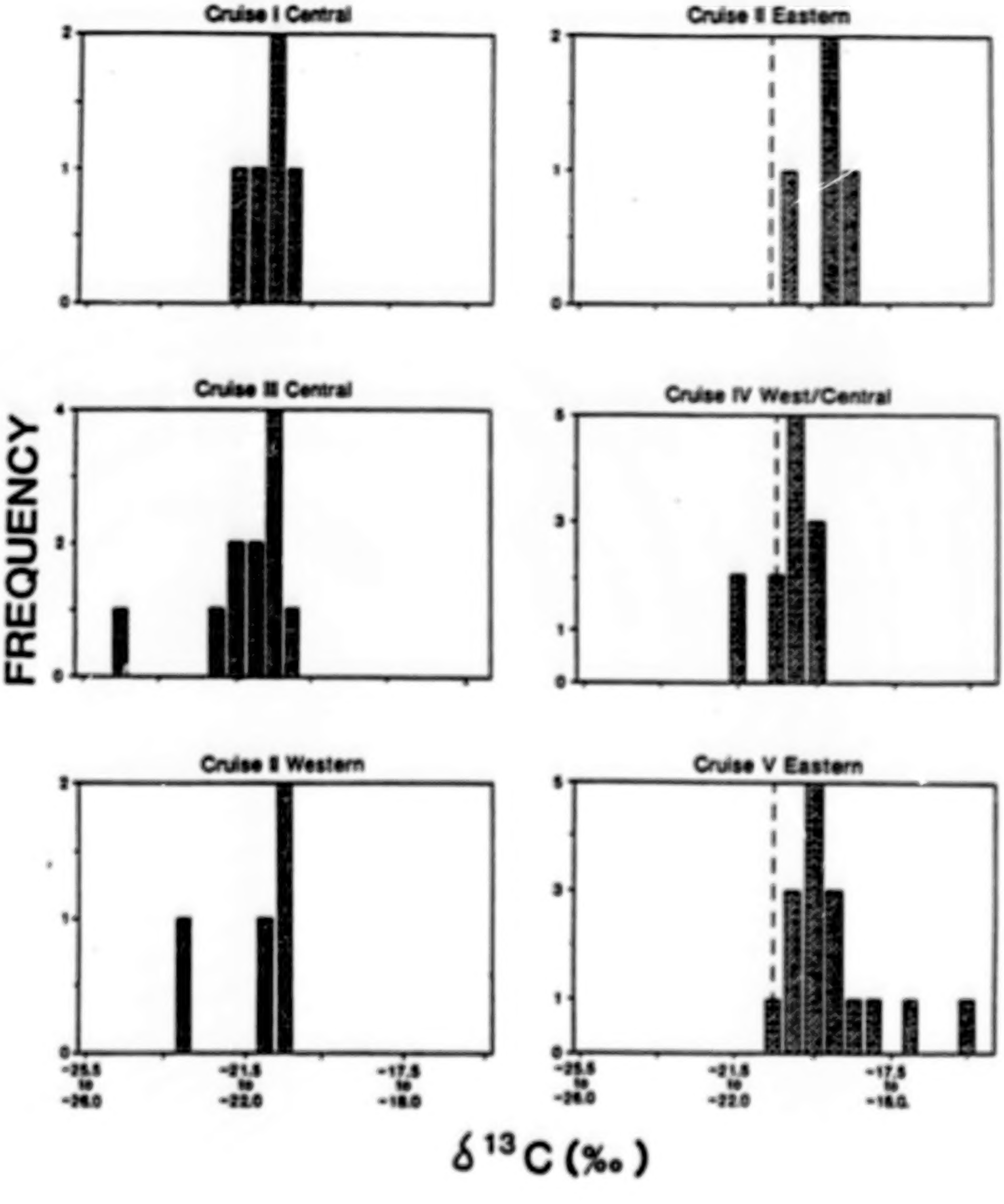


Figure 31. Summary of the carbon isotopic composition of sedimentary organic matter from all five cruises ($\delta^{13}C$ in $^{0}/oo$, vs. Pee Dee Belemite).

factors, in general a more negative carbon isotopic composition suggests greater land influence. Terrestrially sourced organic material, del ^{13}C varies from approximately -25 to -28° °/oo, while planktonic-derived carbon del ^{13}C varies from approximately -16 to -21 °/oo. As can be seen the average del ^{13}C of sedimentary organic material is most positive at the eastern stations, most negative at the Central and Western sampling sites. This trend suggests an increased influence of planktonic material at the eastern sites. In general the average del ^{13}C suggests a substantial planktonic contribution to the bulk organic matter, whereas the hydrocarbons are generally dominated by terrestrial sources.

3.3.2 ORGANISMS

Stable carbon isotopes have been widely used in marine research to trace the flow of carbon in ecosystems and the biogeochemical systems (Parker 1964, Sackett 1964, Calder and Parker 1968, Haines 1976, DeNiro and Epstein 1978, Haines and Montague 1979, Fry and Parker 1979, Fry 1981, Gearing et al. 1984). Several assumptions are inherent in their use including (1) a relatively constant isotopic composition of organic carbon produced by each plant source, (2) an unchanging isotopic ratio in plant carbon as it decomposes and is broken down into detritus, and (3) little or no isotopic fractionation between consumer and its carbon supply. Gearing et al. (1984) have recently provided an excellent review of the carbon isotopic literature relating to these assumptions.

The first assumption is generally applicable within a few parts per thousand for marine plankton. isotopic variability in marine phytoplankton has been correlated with species composition, temperature, water masses, latitude, and del ^{13}C of the inorganic carbon that is fixed. Little isotopic fraction is generally observed in the aerobic decomposition of organic matter in seawater. They observed an overall pattern of increasing carbon isotope ratios with trophic levels, progressing from diatoms (-20.3 °/oo), to zooplankton (-19.8 °/oo), meiofauna (-19.5 °/oo), non-carnivorous macrofauna (-18.6 °/oo), and benthic predators (-16.6 °/oo). Similar patterns have been documented in other studies and support an isotopic shift of a few parts per thousand to more positive values with increasing trophic level. The organism tissue isotopic data for all five cruises is summarized in Figures 32 and 33. Most of the organisms appear predominantly phytoplankton sourced.

3.4 ORGANISM HYDROCARBONS

Hydrocarbon levels in Gulf of Mexico slope organisms were highly variable. Total resolved alkanes in samples from Cruises I, II and III varied from non-detectable to >8000 ppb (Fig. 34). Due to the variety of organisms and organ types analyzed, trends in variations as a function of location, water depth, and time of sampling are difficult to discern. The species collected and analyzed were highly variable thus making direct comparisons difficult if not impossible. No trends in hydrocarbon distributions were evident as a function of any taxonomic group of organisms evaluated (Fig. 34). Of the organisms analyzed, decapods had the lowest incidence of hydrocarbon occurrence in muscle tissue. More than ~75% of the fish muscle tissues analyzed contained detectable hydrocarbons. However, there were no detectable hydrocarbons in several species, primarily shrimp. The sampling was often limited to a single individual and therefore cannot properly represent the entire population.

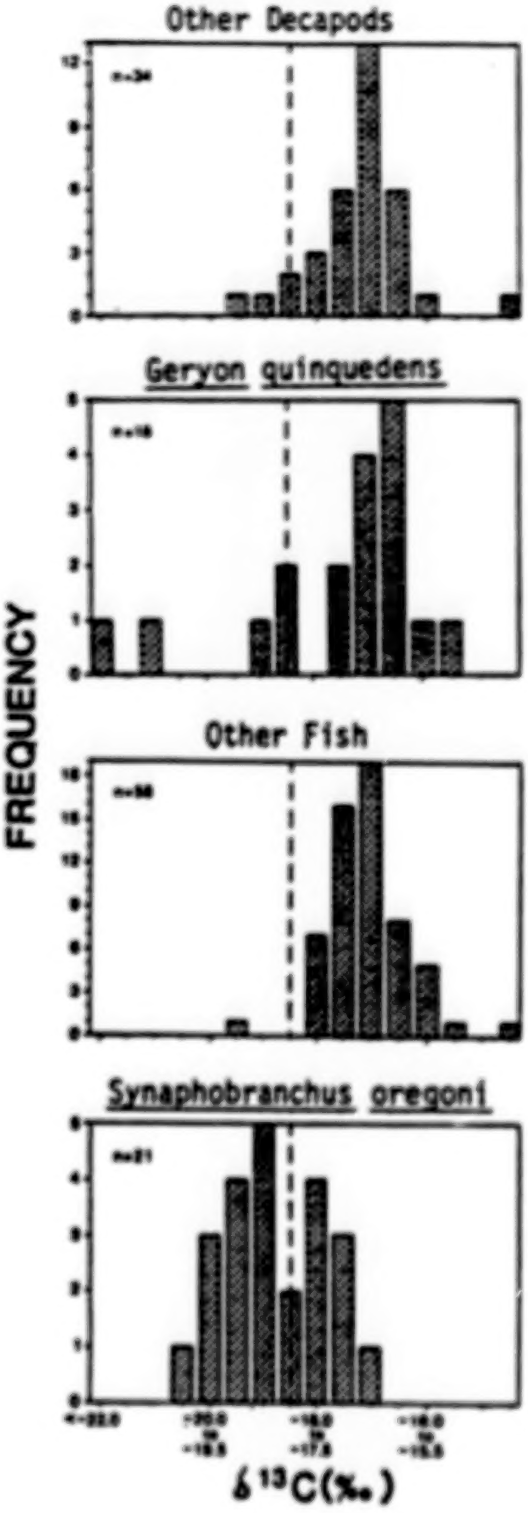


Figure 32. Summary of the carbon isotopic composition of organism tissues by organism type ($\delta^{13}C$ in o/oo vs. PPB).

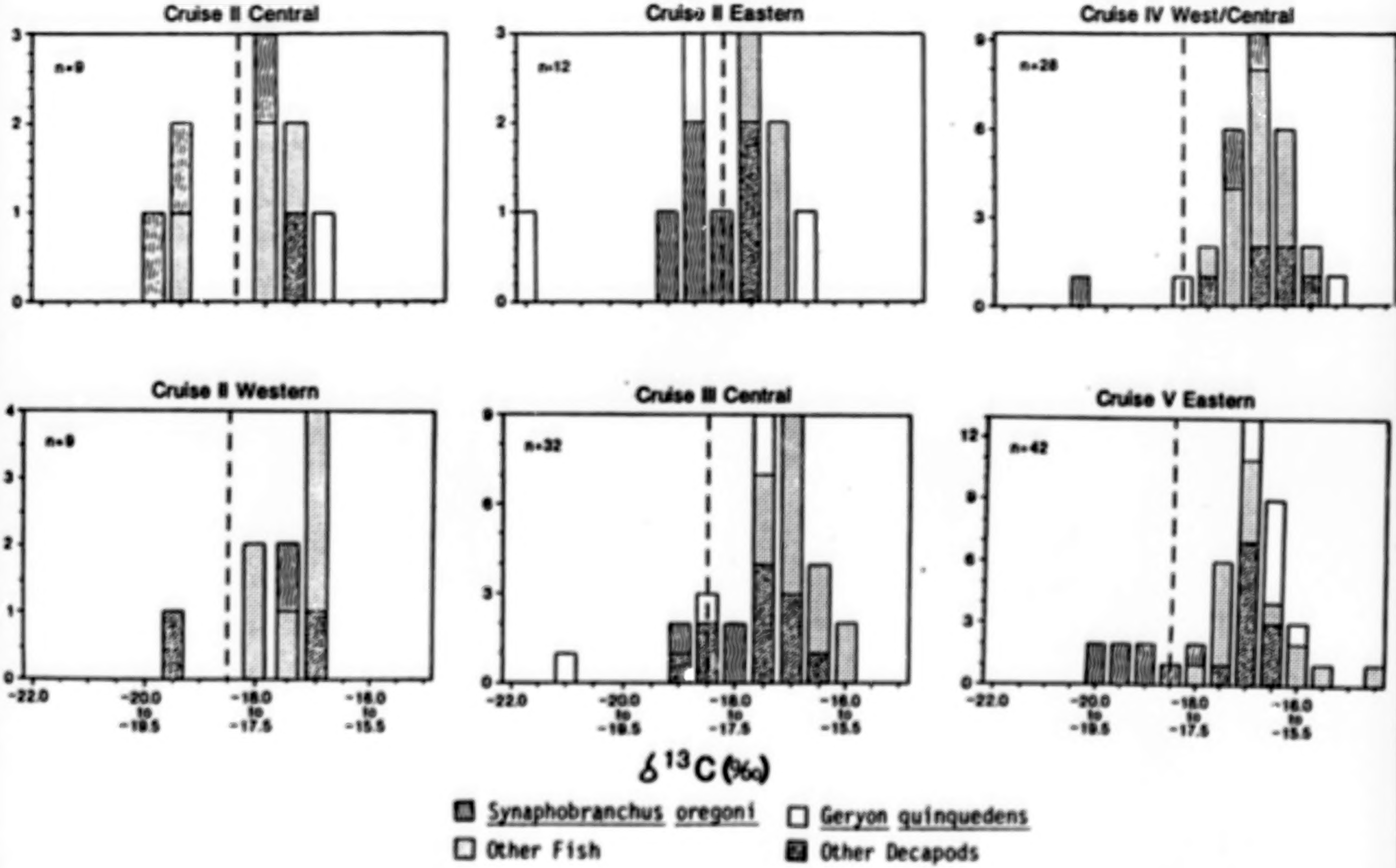


Figure 33. Summary of the carbon isotopic composition of organism tissues by transect and organism type for all five cruises ($\delta^{13}C$ in o/oo vs. PPB).

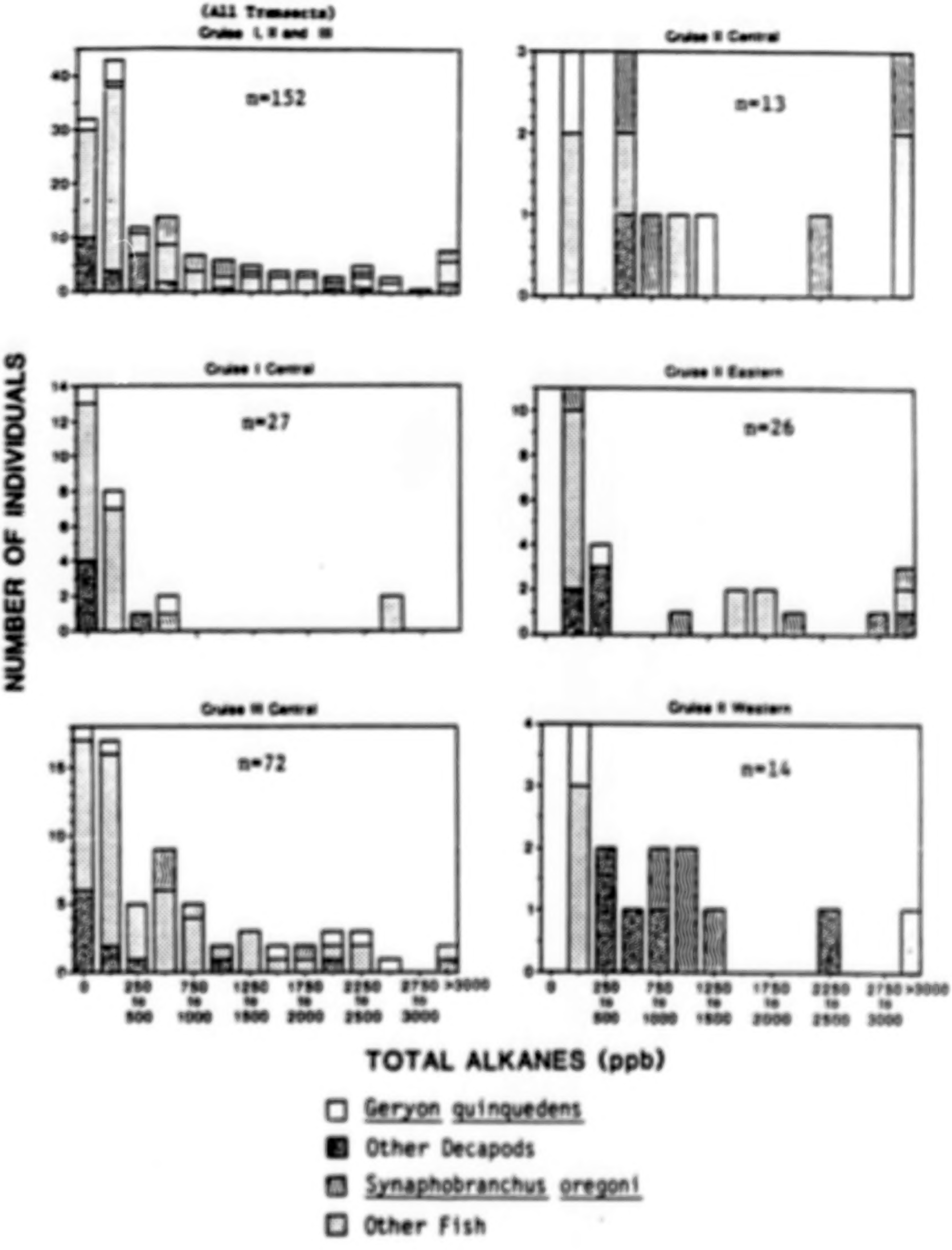


Figure 34. Summary of the total alkane concentration in organism tissues for Cruises I, II and III.

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4.0 BIOLOGICAL OCEANOGRAPHY OF THE NORTHERN GULF OF MEXICO CONTINENTAL SLOPE

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4.0 BIOLOGICAL OCEANOGRAPHY OF THE NORTHERN GULF OF MEXICO CONTINENTAL SLOPE

The faunal groups discussed in this study include the meiofauna (0.063-0.3 mm), collected by box corer, the macrofauna (greater than 0.3 mm in size) also collected by box corer, and the megafauna (both invertebrates and demersal fishes), which were collected by trawling. Of these groups, only the meiofauna and certain macrofaunal groups, such as Nematoda, Harpacticoida, Kinorhyncha, and a few others, were not identified to the species level.

The results of the five cruises discussed in this report suggest that it is now possible to predict with a reasonable degree of certainty the basic composition of the faunal communities on the northern Gulf slope between the 300 and 2500-m isobaths lying between 85° and 94° west longitude. Furthermore, it is also evident that there is a reasonable degree of agreement between the faunal findings discussed in a previous MMS study of the Gulf (Pequegnat 1983) and the present MMS study conducted by LGL. This is not to say that significant new discoveries have not been made, for they have. For instance, the discovery of the "seep communities" in the northcentral Gulf goes well beyond the recognition of a unique kind of community in that it shows that matter and energy reductions can be a major factor limiting community developments in the deep sea. Also, it is very important to note that new species of organisms have been uncovered during every cruise. The numbers of new species in such macrofaunal groups as the Tanaidacea, Cumacea, and Ectoprocta, to mention but a few, were not anticipated. Very likely the same would be true of the meiofauna were we to study it intensively. More surprising, perhaps, is the fact that a rather large number of new species and first records for species were revealed by a careful study of the megafaunal decapods alone. For instance, two new species of galatheids (in the genera Munidopsis and Phylladiorhynchus) are being described (L.E. and W.E. Pequegnat), two new species of brachyuran crabs in the genus Cymonomus are being described by D. Felder, a new pagurid in the genus Parapagurus is being described by R. Lemaitre, and two new species of carideans, viz., Bythocaris sp. A, and Palaemonella sp. A are being described by R. Heard.

The number of species of decapods found for the first time in the Gulf or that are considered extremely rare by specialists is too large to detail here, but the tally is an impressive one. A complete list of the species identified from Cruises I-V from all sampling efforts can be found in Volume III of this report series.

4.1 MEIOFAUNA

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4.1 MEIOFAUNA

A total of 43 major groups of meiofauna were identified. Of these, representatives of five taxa of permanent meiofauna (Nematoda, Harpacticoida, Polychaeta, Ostracoda, and Kinorhyncha) along with temporary meiofauna (naupliar larvae) comprised 98% of the meiofauna collection. Counts of protozoan Foraminifera were not included in analysis of the meiofauna. Nematoda were the numerically dominant taxon throughout the collection; however, the larger, but less abundant Polychaeta were the dominant contributer to the meiofauna biomass at most stations.

Figure 29 shows regressions of the log of the numbers of meiofauna and macrofauna plotted against depth for all stations in the study. The density of the meiofauna was approximately two orders of magnitude greater than the density of macrofauna throughout the depth range sampled. The densities of meiofauna were similar to those reported by previous studies at slope depths in the southeast Atlantic and the Gulf of Mexico (Theil 1983). Density of meiofauna generally decreased with increasing depth; however, there was considerable variation among replicated samples. The decrease in density with increasing depth was most constant among the Central Transect sampling stations and most variable among the Eastern Transect stations. The regression plots in Figure 35 suggest that there was a three-fold decrease in the density of meiofauna and a two-fold decrease in the density of macrofauna between 300 and 3000 m depths.

Figure 35 also shows regressions of the log of approximate wet weight for meiofauna and macrofauna. Approximate wet weights per m^2 were calculated by multiplying the densities of each of the 43 meiofaunal and 44 macrofaunal groups, respectively, by appropriate estimates of wet weight per individual (Rowe et al. 1974, Fauble 1982). As with density, the approximate wet weight of both groups decreased with increasing depth. In this case, however, the rate of decrease for macrofauna was slightly greater than for meiofauna. The regression plots in Figure 35 suggest that there was a three-and-one-half-fold decrease in the biomass of meiofauna and a four-fold decrease in the biomass of macrofauna between 300 and 3000 m depths.

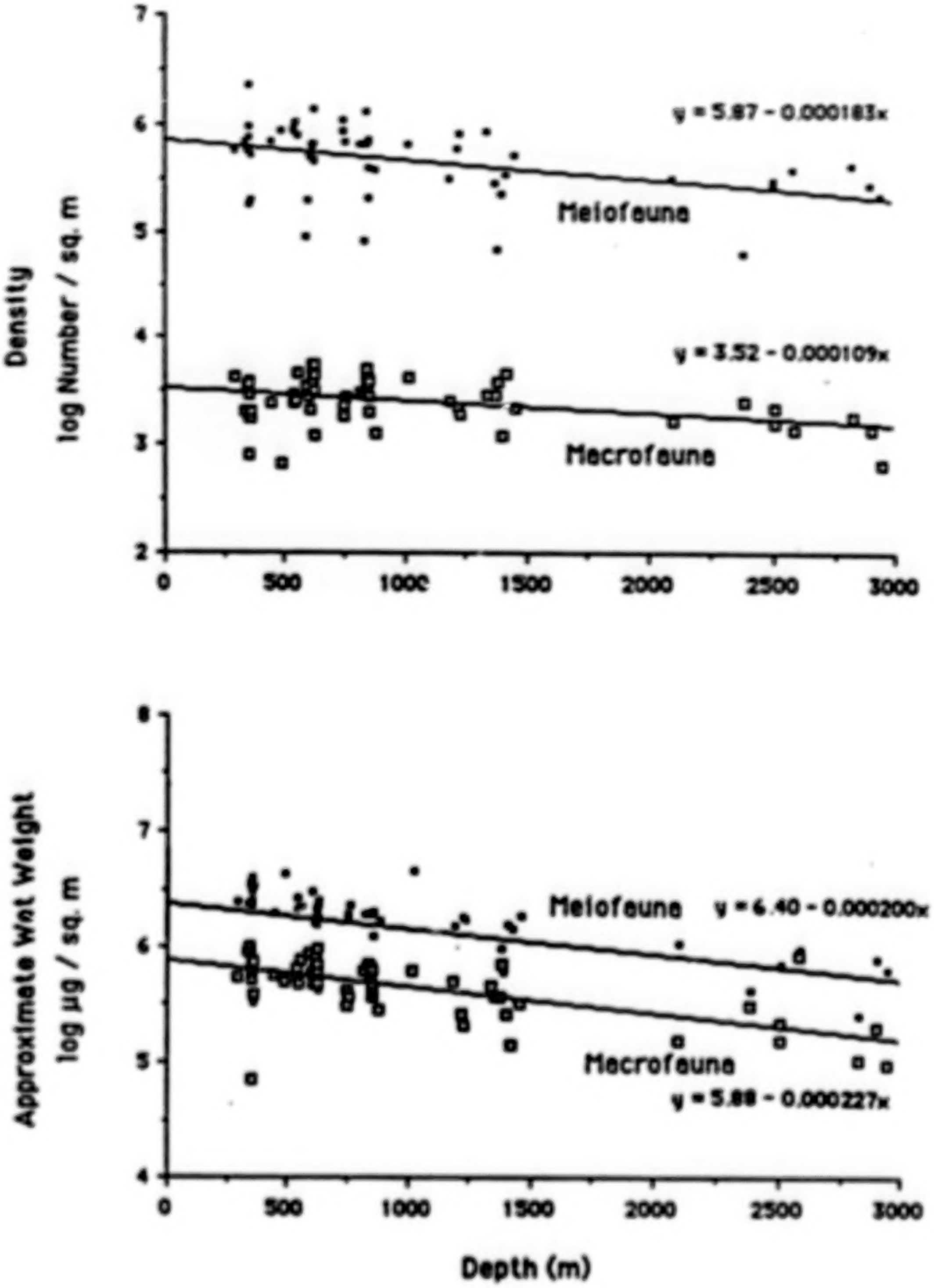

Figure 35. Relative occurrence of meiofauna and macrofauna with depth at all sampling stations. Upper plot shows log of density per square meter. Lower plot shows log of approximate biomass per square meter.

4.2 MACROFAUNA

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4.2 MACROFAUNA

4.2.1 INTRODUCTION

Macrofauna was defined arbitrarily for the purposes of this study as those organisms collected with box corers and retained on a 0.3 mm sieve and thus represent much smaller sizes than one typically finds in other macrofauna samplings which have used 0.5 mm or 0.42 mm sieves.

Samples from the macrofaunal component of box cores contained 18 phyla, which were separated into 1569 differentiable taxa. Specimens were routinely identified to the lowest possible taxon, except for those belonging to three major groups in which severe taxonomic difficulties were encountered: Copepoda (primarily harpacticoid copepods), Aplacophora, and Scyphozoa.

Species-level identification was attempted for all but the three groups of macrofauna mentioned above. For these groups, approximately 90% of the individuals were identified either to genus or to species; 71% of the taxa were identified to species. Specimens that could not be identified to species were usually either a) juveniles that had not yet developed the requisite taxonomic characteristics, or b) specimens that no longer possessed in an intact form the morphological structures necessary for positive identification. Loss through autotomy or damage to some structures (e.g. microscopic appendages on crustaceans) is an unavoidable consequence of collection and preservation for some of the more delicate species, no matter how carefully the samples are handled. The small sizes of the macrofaunal specimens from this study were remarked upon by most of the taxonomic specialists, making identification to the lower taxonomic levels much more difficult because in most cases the small sizes represented immature specimens.

Nearly all macrofaunal species were infaunal invertebrates, although some forms commonly found on surficial sediments (nominally "epifauna") such as ophiuroids and echinoids were taken by the box corers. There were more annelid taxa than any other major group of organisms. Nine oligochaete and 626 polychaete taxa were identified, accounting for over 40% of the total number of taxa.

4.2.2 COMMUNITY STRUCTURE

Table 4 lists the 40 major macrofaunal groups in decreasing order of total numerical abundance over all five cruises, for all stations together. It also gives information on number of taxa identified in each group, and relative numbers of taxa identified to the specific, generic, and higher taxonomic levels.

Specimens belonging to the first 20 groups accounted for 99% of the total number of individuals collected. Six taxonomic groups (Polychaeta, Ostracoda, Bivalvia, Tanaidacea, Bryozoa, and Isopoda) accounted for 86% of the total numerical abundance. Counts of bryozoans mainly included single, more-or-less intact colonies. An attempt was made to avoid overestimating bryozoan abundance by not counting multiple, broken pieces of colonies. At the species level, most macrofaunal taxa were represented by very few individuals (Fig. 36). For example, over 550 species, excluding the polychaetes, were collected five or fewer times (only 1 to 5 individuals total, for all samples combined).

Table 5 lists in rank order the dominant 50 species occurring at all macrofaunal stations combined. The list includes 28 species of polychaetes, six bivalve mollusks, three species of ostracodes, two isopods, two amphipods, one sponge, and one nemertean worm.

4.2.3 MACROFAUNA ABUNDANCE PATTERNS

Based upon preliminary calculations, the overall density levels of macrofauna among study area sampling stations (not including nematodes, non-myodocopan ostracods and copepods, considered meiofauna) ranged from about 518 specimens/m^2 (Station C12, Cruise III) to 5369 specimens/m^2 (Station E2E, Cruise IV). As noted, these overall density estimates are preliminary. Other than excluding some obvious meiofaunal forms retained on occasion in the macrofauna sieve, we have not, as yet, examined the collection lists and deleted other forms that should not, by convention, be included in our macrofauna designation. These changes, once made, are not expected to have any detectable effects on the overall abundance trends.

Table 4. Relative abundance of major macrofaunal groups.

Taxonomic group	No. Individuals	Total No. Individual Forms	No. Iden. To Species	No. Iden. To Genus	No. Iden. To Family Or Higher Taxa
POLYCHAETA	24313	626	414	163	49
OSTRACODA	4960	19	18	1	0
BIVALVIA	3645	55	41	10	4
TANAIDACEA	3610	186	168	13	5
BRYOZOA	3049	99	82	12	5
ISOPODA	2327	133	119	8	6
AMPHIPODA	1285	79	50	11	18
APLACOPHORA	886	1	0	0	1
NEMERTEA	630	21	20	0	1
OPHIUROIDEA	603	17	13	3	1
SIPUNCULA	570	37	31	3	3
CUMACEA	521	86	76	8	2
PORIFERA	424	39	22	10	7
SCAPHOPODA	382	10	5	2	3
SCYPHOZOA	331	1	0	0	1
GASTROPODA	276	53	8	27	18
HOLOTHUROIDEA	250	13	4	4	5
OLIGOCHAETA	247	9	6	1	2
ASCIDIACEA	136	18	11	3	4
HYDROZOA	103	15	8	3	4
BRACHIOPODA	79	2	2	0	0
ARACHNIDA:ACARINA	62	1	0	0	1
KINORHYNCHA	60	3	0	2	1
ECHINOIDEA	49	6	3	1	2
PRIAPULIDA	33	1	0	0	1
SCLERACTINEA	33	6	4	1	1
DECAPODA	25	13	10	1	2
MYSTACOCARIDA	12	1	0	0	1
POGONOPHORA/VESTIMENT.	11	1	0	0	1
ECHIURA	9	1	0	0	1
ACTINIARIA	8	3	0	0	3
ALCYONARIA	8	2	1	0	1
TURBELLARIA	8	1	0	0	1
CRINOIDEA	7	2	2	0	0
PYCNOGONIDA	7	3	3	0	0
HEMICHORDATA	4	1	0	0	1
ASTEROIDEA	2	2	0	1	1
MISC. ANTHOZOA	2	1	0	0	1
MYSIDACEA	2	1	0	0	1
ARCHIANNELIDA	1	1	0	0	1
Total	**48970**	**1569**	**1121**	**288**	**160**

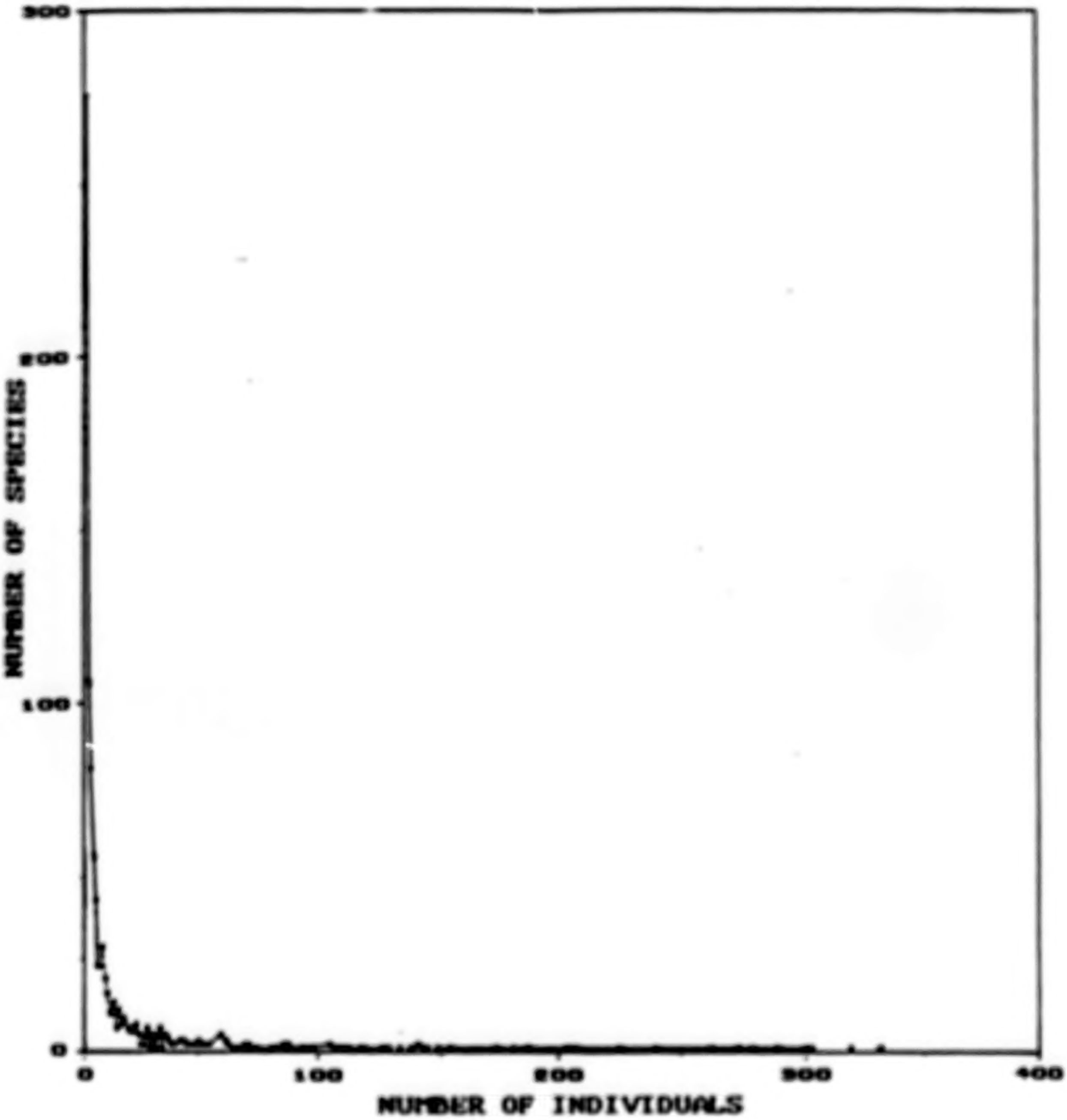

Figure 36. Plot of number of macrofaunal species versus number of individuals showing the great number of species that were collected few times compared to the fewer species that occurred in large numbers.

Table 5. Rank order of dominant macrofaunal species.

SPECIES	GROUP	OVERALL DENSITY (no/m^2)	NO. OF INDIVIDUALS	NO. OF STATIONS	DEPTH RANGE (m)
Nolella monniotae	Bryozoa	112	1772	27	298-2901
Litocorsa antennata	Polychaeta: Pilargidae	78	1209	30	298- 881
Aurospio dibranchiata	Polychaeta: Spionidae	77	1190	49	298-2827
Maldane sp.	Polychaeta: Maldanidae	46	715	15	298-1465
Aedicira sp.	Polychaeta: Paraonidae	44	679	53	298-2945
Tachytrypane sp. A	Polychaeta: Opheliidae	37	571	51	298-2518
Spiophanes berkeleyorum	Polychaeta: Spionidae	33	505	52	298-2901
Exogone "sp. A"	Polychaeta: Syllidae	30	467	53	344-2945
Aricidea suecica	Polychaeta: Paraonidae	27	421	54	298-2945
Pholoe "sp. C"	Polychaeta: Sigalionidae	27	417	29	344-1021
Maldane "sp. A"	Polychaeta: Maldanidae	26	402	16	298-1465
Prionospio ehlersi	Polychaeta: Spionidae	24	380	37	344-1465
Levinsenia gracilis	Polychaeta: Paraonidae	24	371	53	298-2945
Euphilomedes sp. A	Crustacea: Ostracoda	21	332	23	453- 860
Eulamellibranchia sp. F	Mollusca: Bivalvia	20	319	34	298- 860
Pseudotanais sp. 1	Crustacea: Tanaidacea	19	299	52	298-2945
Euginoma cavalieri	Bryozoa	18	289	37	298-2506
Fauveliopsis sp. B	Polychaeta: Fauveliopsidae	18	283	49	298-2945
Angulorostrum sp. A	Crustacea: Ostracoda	18	279	44	298-1465
Sarsonuphis hartmanae	Polychaeta: Onuphidae	18	276	49	298-1465
Nolella sp.	Bryozoa	17	273	22	353-2945
Prionospio cirrifera	Polychaeta: Spionidae	18	272	30	298-2506
Vesicomya sp.	Mollusca: Bivalvia	17	262	40	344-2389
Malletia sp. B	Mollusca: Bivalvia	15	239	29	298-1381
Tharyx marioni	Polychaeta: Cirratulidae	15	231	52	298-2945
Lumbrineriides dayi	Polychaeta: Lumbrineridae	15	229	48	298-2945
Crenella sp. A	Mollusca: Bivalvia	14	225	34	547-1465
Ceratocephale oculata	Polychaeta: Nereidae	14	220	45	329-2901
Paralacydonia paradoxa	Polychaeta: Lacydoniidae	14	211	37	298-1290
Nucula sp. A	Mollusca: Bivalvia	13	208	46	329-1465
Philomedes sp. A	Crustacea: Ostracoda	13	203	19	344- 838
Leitoscoloplos sp. A	Polychaeta: Orbiniidae	13	196	20	298-1430
Tharyx cf. *annulosus*	Polychaeta: Cirratulidae	12	191	42	298-2901
Paramphinome jeffreysii	Polychaeta: Amphinomidae	12	188	47	298-2475
Mesotanais sp. 1	Crustacea: Tanaidacea	11	181	34	329-1390
Leptognathia sp. 15	Crustacea: Tanaidacea	11	173	37	344-2901
Terebellides stroemi	Polychaeta: Trichobranchidae	11	173	35	298-2518
Diplocirrus capensis	Polychaeta: Flabelligeridae	11	168	42	298-2389
Pionosyllis "sp. N"	Polychaeta: Syllidae	10	161	27	298-1021
Apseudidae A	Crustacea: Tanaidacea	10	154	19	359-1465
Aricidea sp.	Polychaeta: Paraonidae	10	155	41	298-2518
Terebellides atlantis	Polychaeta: Trichobranchidae	10	153	32	329-1465
Gnathia sp. 201	Crustacea: Isopoda	9	149	9	344-1226
Pardisynopia n. sp. 1	Crustacea: Amphipoda	9	145	36	547-2901
Phoxocephalidae sp. 1	Crustacea: Amphipoda	9	143	30	298-1465
Ischnomesus sp. 208	Crustacea: Isopoda	9	141	28	453-1381
Cuspidaria sp.	Mollusca: Bivalvia	9	141	33	298-2945
Stelletta sp.	Porifera	8	134	25	298-1465
Nemertea sp. CL4	Nemertea	8	130	47	298-2827
Spionidae Genus B	Polychaeta: Spionidae	10	130	14	298- 759

The overall region, season, year by depth patterns of macrofaunal abundance are shown by Figure 37. From inspection, abundance appears somewhat higher on the Central Transect (x=3156/m^2) than on either the Eastern (x=2695/m^2) or Western Transects (x=2100/m^2). Based upon the data from the Central Transect, spring abundance levels (3156/m^2) appeared higher than fall abundance levels (x ranged from 1657 to 1987/m^2). The annual differences between the fall collections of 1983 and 1984 on the Central Transect and the spring collections of 1984 and 1985 on the Eastern Transect were 330 and 169/m^2, respectively. This compares to regional differences ranging between 461 and 1056/m^2, and seasonal differences ranging from 1169 to 1499/m^2. Annual differences appear less than regional and seasonal variation in abundance.

On both the Eastern and Western Transects, an overall decline of macrofaunal density with depth is clearly indicated, even though there are some exceptions at the shallower of the sampled depths (Fig. 37). On the Central Transect, the observed trend of abundance decrease with depth is interrupted by an apparent abundance peak at the 1400-m deep station. Increased sampling intensity on the Central Transect, not only validated the 1400-m peak, but yielded data suggesting even higher abundance was present at about 1000-m depths (Fig. 38). These apparent differences will be examined in detail in the Year 4 Final Report. Suffice it to say now that we believe the "anomalous" abundance peaks to be related to physiography and/or proximity to chemosynthetic seep communities.

Results of sampling along isobaths in both the Eastern (Fig. 39) and Western (Fig. 40) Transects yielded consistent results in terms of overall density, except for some of the planned contrasts of sediment type, proximity to seep communities and topographic features. The exceptions were unexpected low densities at Stations E2D and E3 on the Eastern Transect. All of these differences (those accountable by design and those unexpected) will be evaluated in the Year 4 Annual Report.

4.2.4 MACROFAUNA DIVERSITY PATTERNS

The diversity evaluations made in this report are based upon comparisons of the H' index applied to data for species only. From review of these data and supporting indices (evenness and richness) it is

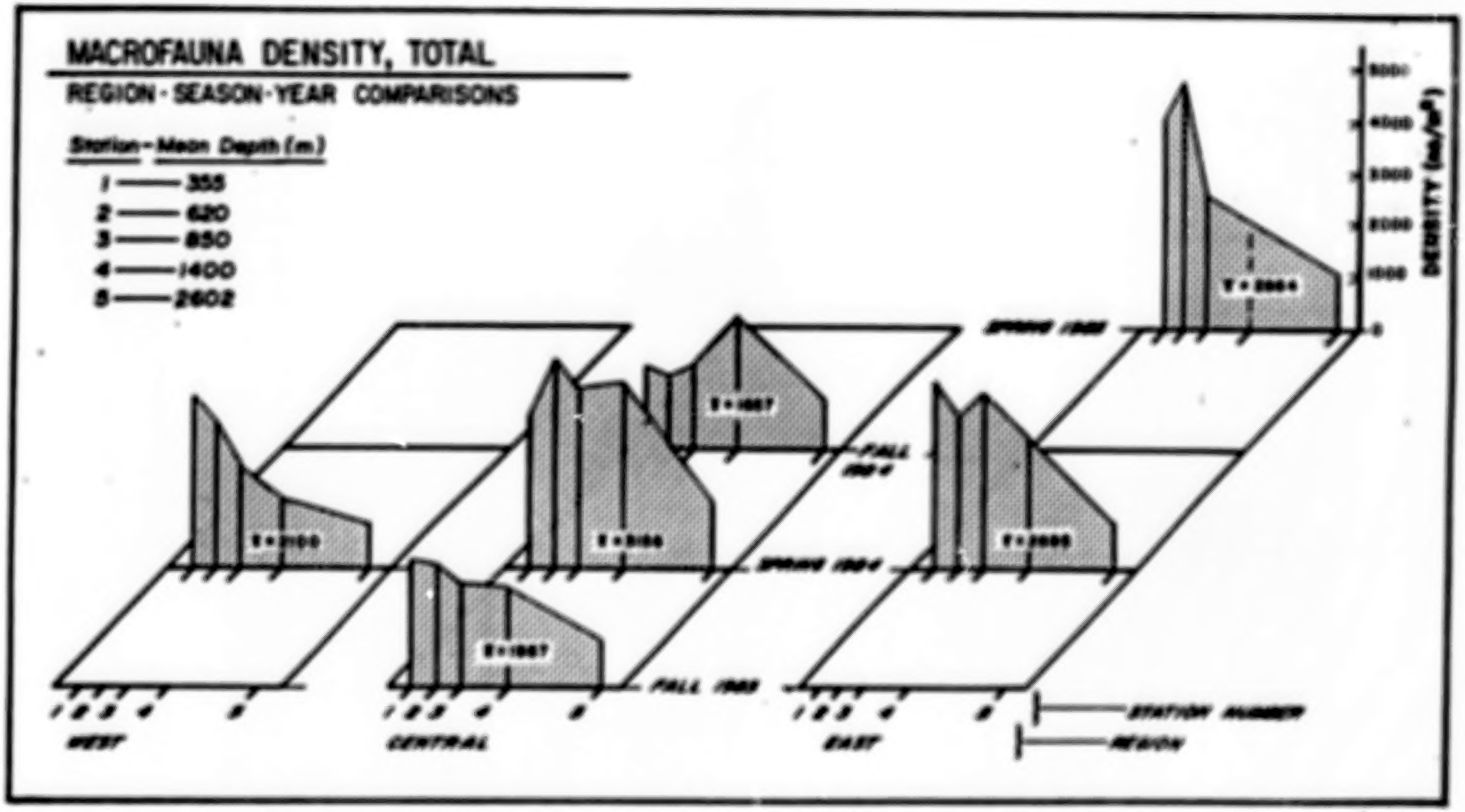

Figure 37. Comparative levels of macrofaunal densities by region, season, year and selected depth interval.

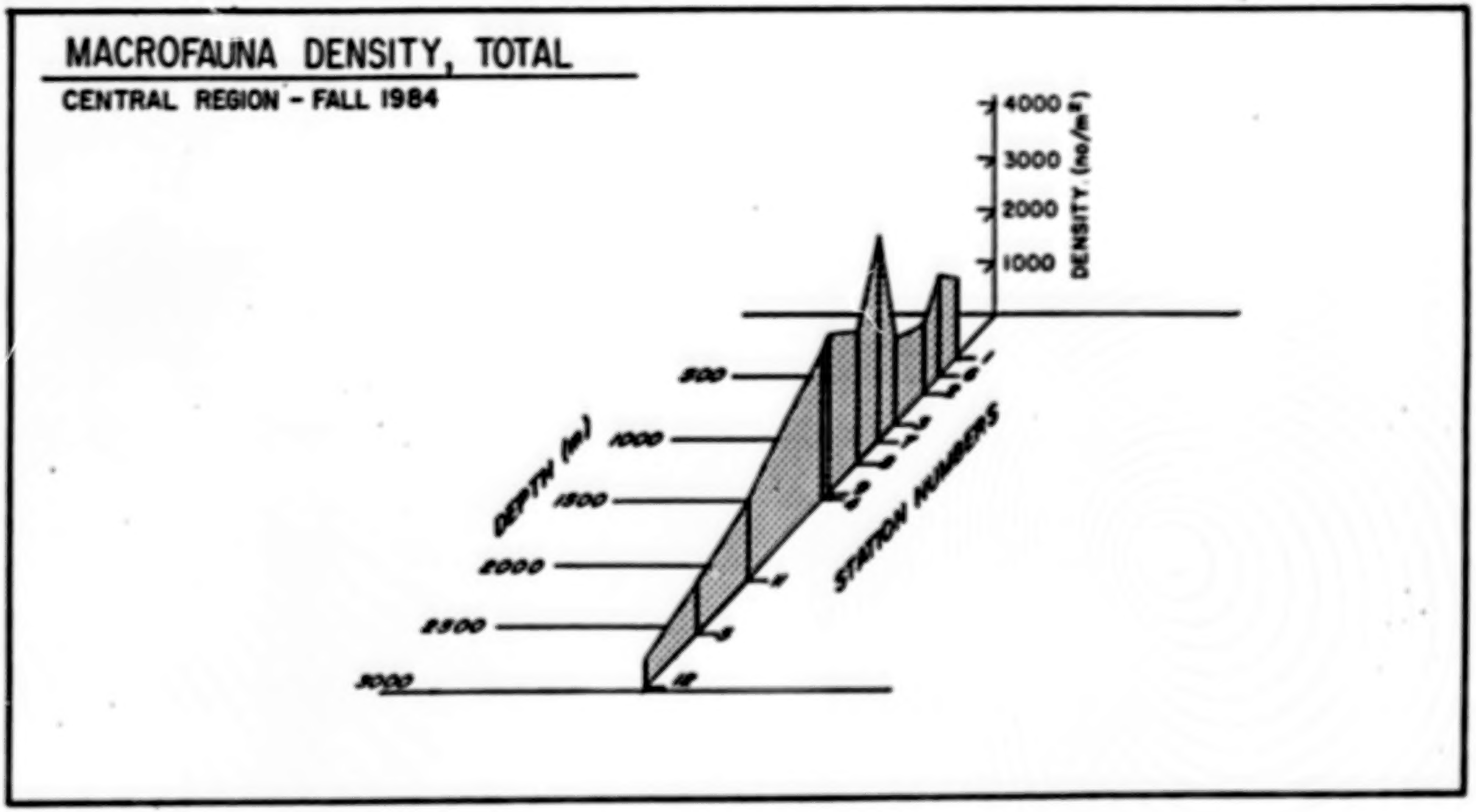

Figure 38. Comparative levels of macrofaunal density by depth on the Central Transect, Fall 1984.

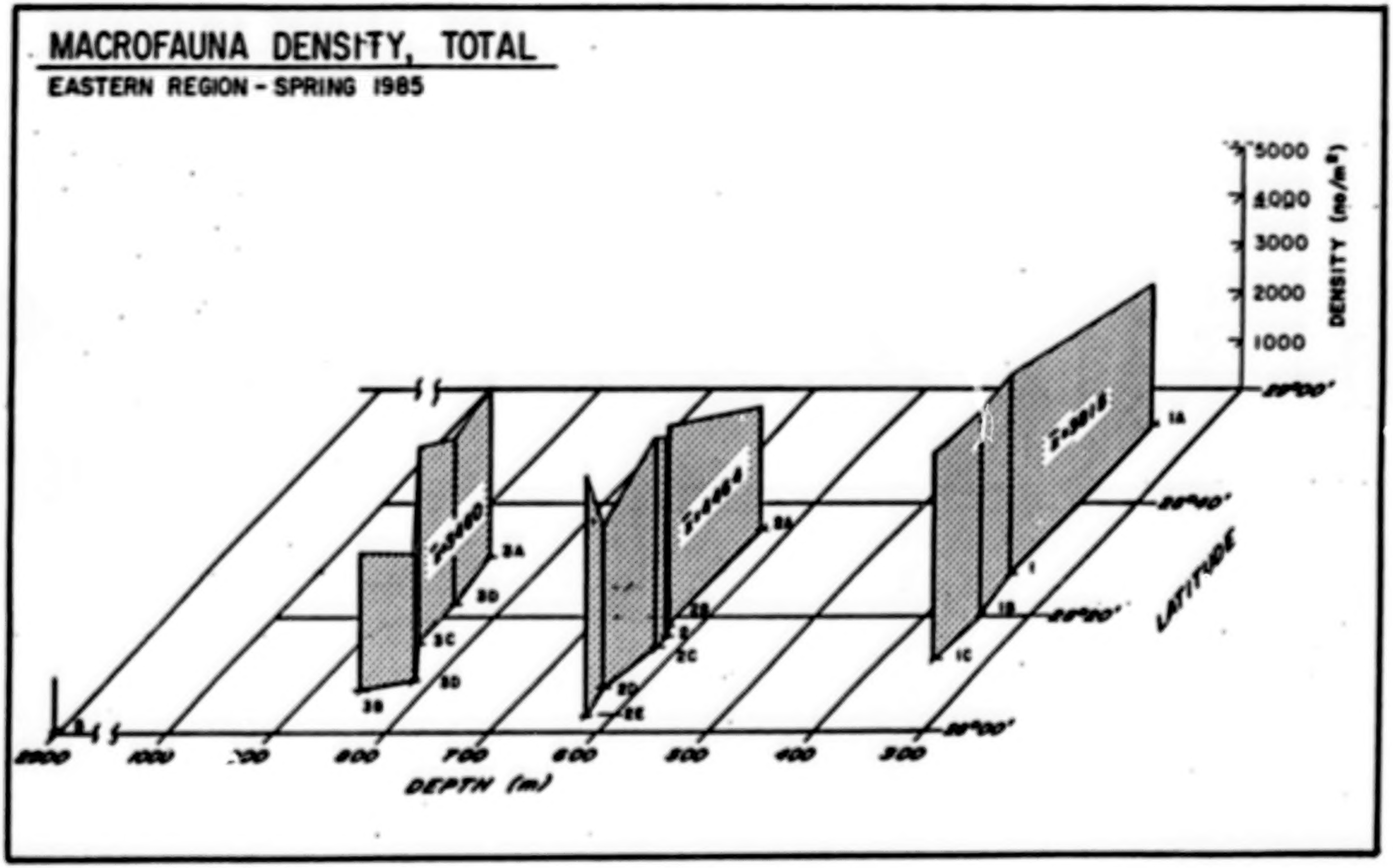

Figure 39. Comparative levels of macrofaunal density along selected isobaths in the Eastern Gulf of Mexico during Spring 1985.

105

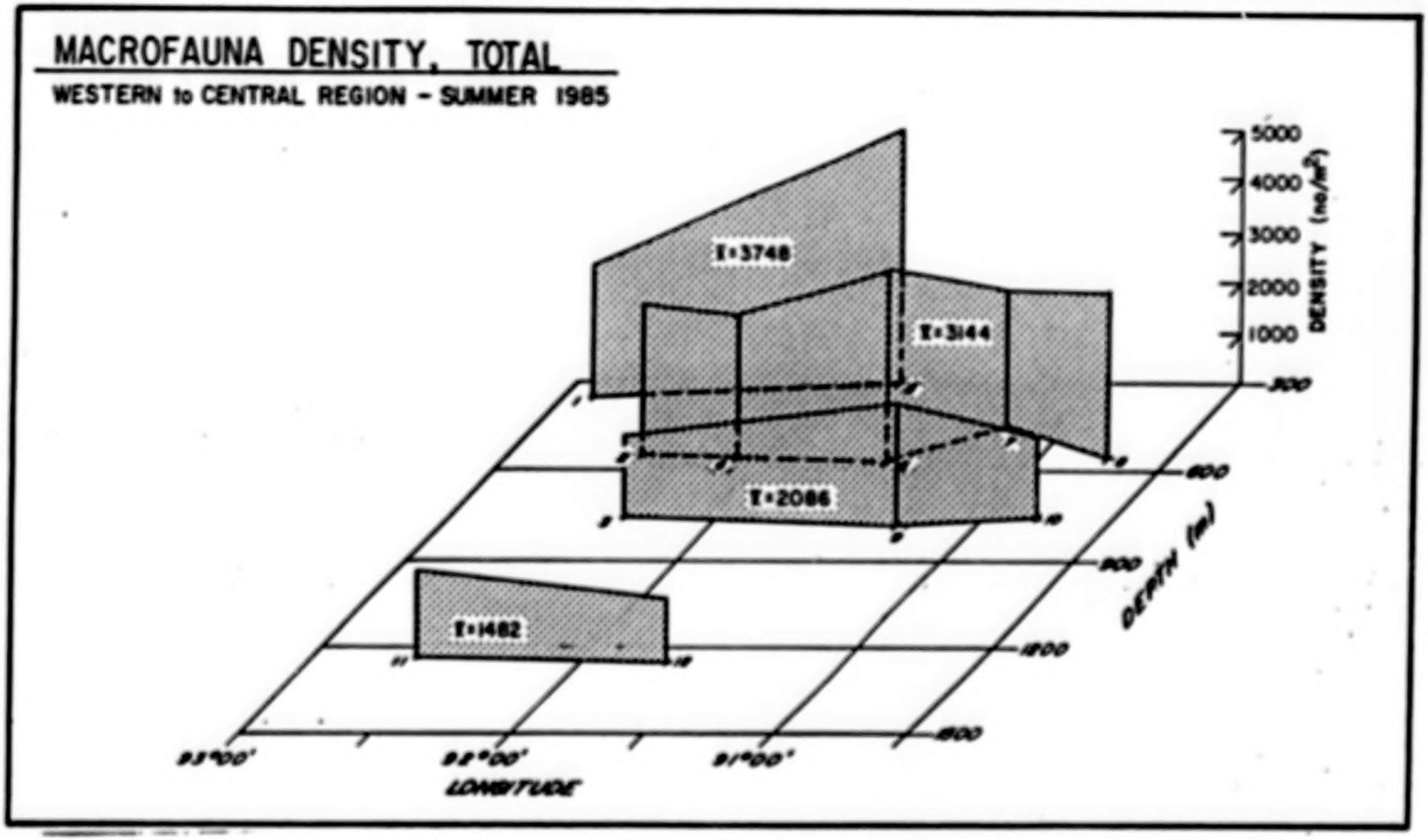

Figure 40. Comparative levels of macrofaunal density along isobaths between the Central and Western Gulf of Mexico sampling transects, Summer 1985.

apparent that most of the differences in the overall index are attributable to the richness aspect, which is greatly influenced by sample size. In the Year 4 report, rarefaction analysis will be used to offset the confounding effects of sample size on the diversity evaluations.

The regional, seasonal and yearly patterns of macrofaunal diversity by depth are presented in Figure 41. Although the trends are not pronounced, diversity appears to decrease from east to west and to have been somewhat higher in fall than in spring on the Central Transect. Differences in fall diversity levels between years on the Central Transect were negligible, but spring 1985 diversity levels on the Eastern Transect were marginally higher than spring 1984 levels (Fig. 41).

The most consistent depth trend was a marked decrease in diversity between the 1400-m deep and 2600-m deep stations on each transect. There also appears a tendency of a slight diversity increase between the shallowest station (~350 m) and some of the sequentially deeper stations, yielding somewhat skewed, dome-shaped diversity curves over the depth range sampled.

The data obtained from sampling a higher density of stations on the Central Transect in fall 1984 enabled a more detailed examination of macrofauna diversity levels over the sampled interval (Fig. 42). Diversity appeared to increase slightly from Station 1 (355 m deep) to Station 3 (850 m deep), and from there decreased with depth down to Station 9 (1428 m deep). A slight peak was observed at Station 4 (1465 m deep), after which the diversity level once more declined gradually over the depth interval between 1465 m and 2945 m (Fig. 42).

As shown by Figures 43 and 44, macrofauna diversity levels were rather constant along the sampled isobaths in both the eastern and western regions where these studies were conducted. Additionally, there appeared very little variation by depth, at least within the intervals sampled.

4.2.5 MAJOR GROUP ACCOUNTS

Volume II: Technical Report, the 32 animal groups that accounted for 99.9% of the total macrofaunal collections are discussed individually, namely: Porifera, Hydrozoa, Scyphozoa, Actiniaria, Alcyonaria, Scleractinia, Nemertea, Kinorhyncha, Nematoda, Polychaeta, Oligochaeta,

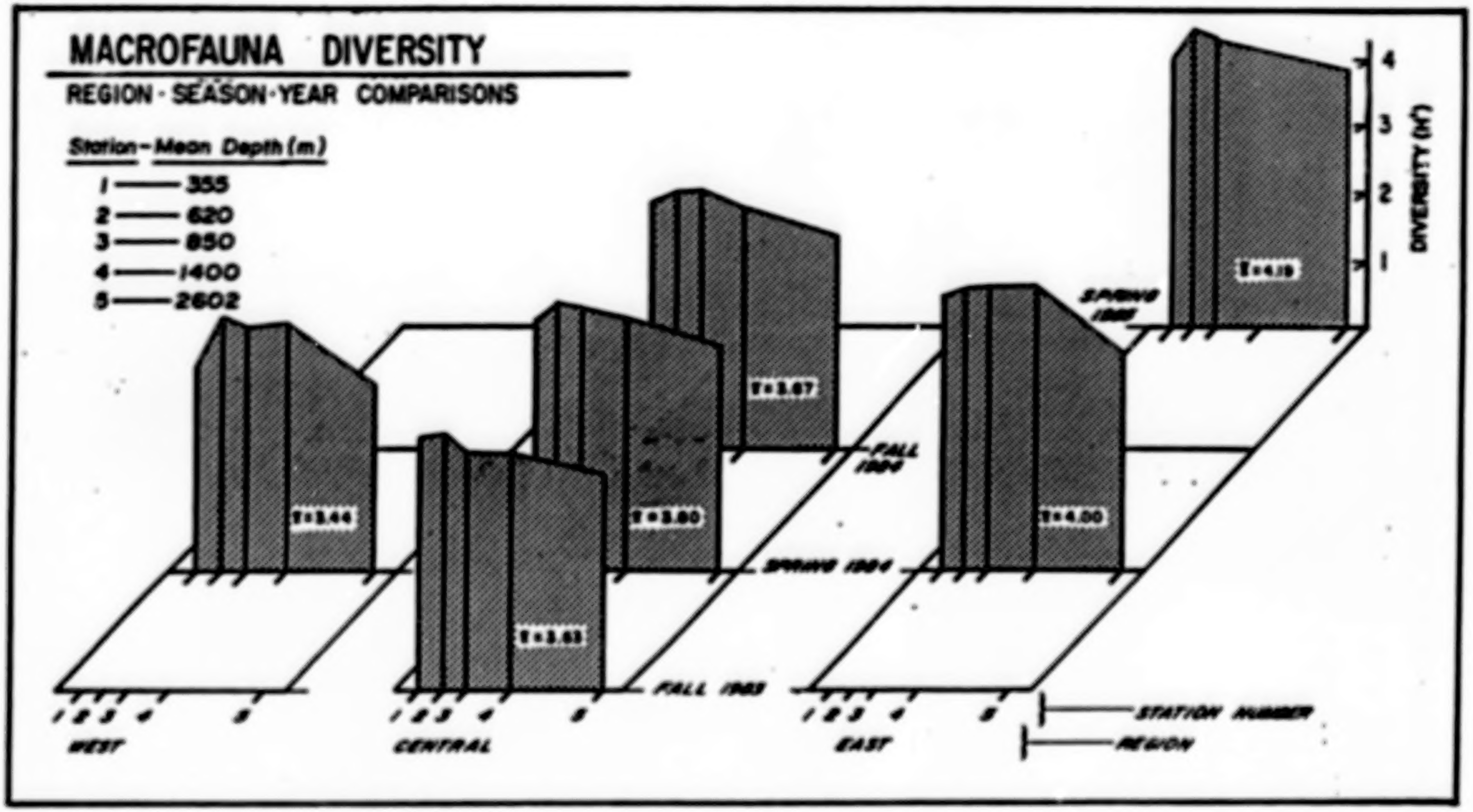

Figure 41. Comparative levels of macrofaunal diversity by region, season, year and selected depth interval.

108

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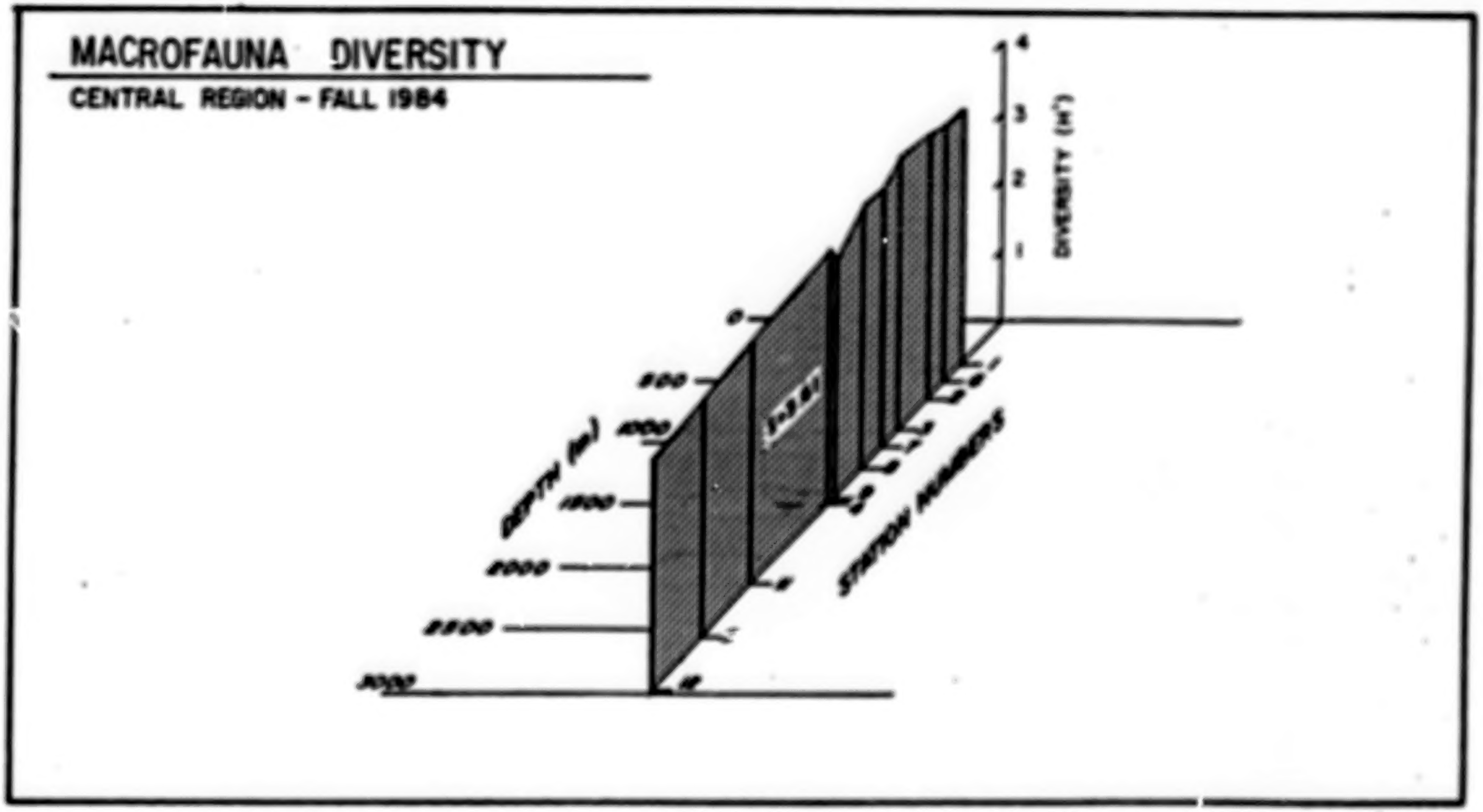

Figure 42. Comparative levels of macrofaunal diversity by depth on the Central Transect, Fall 1984.

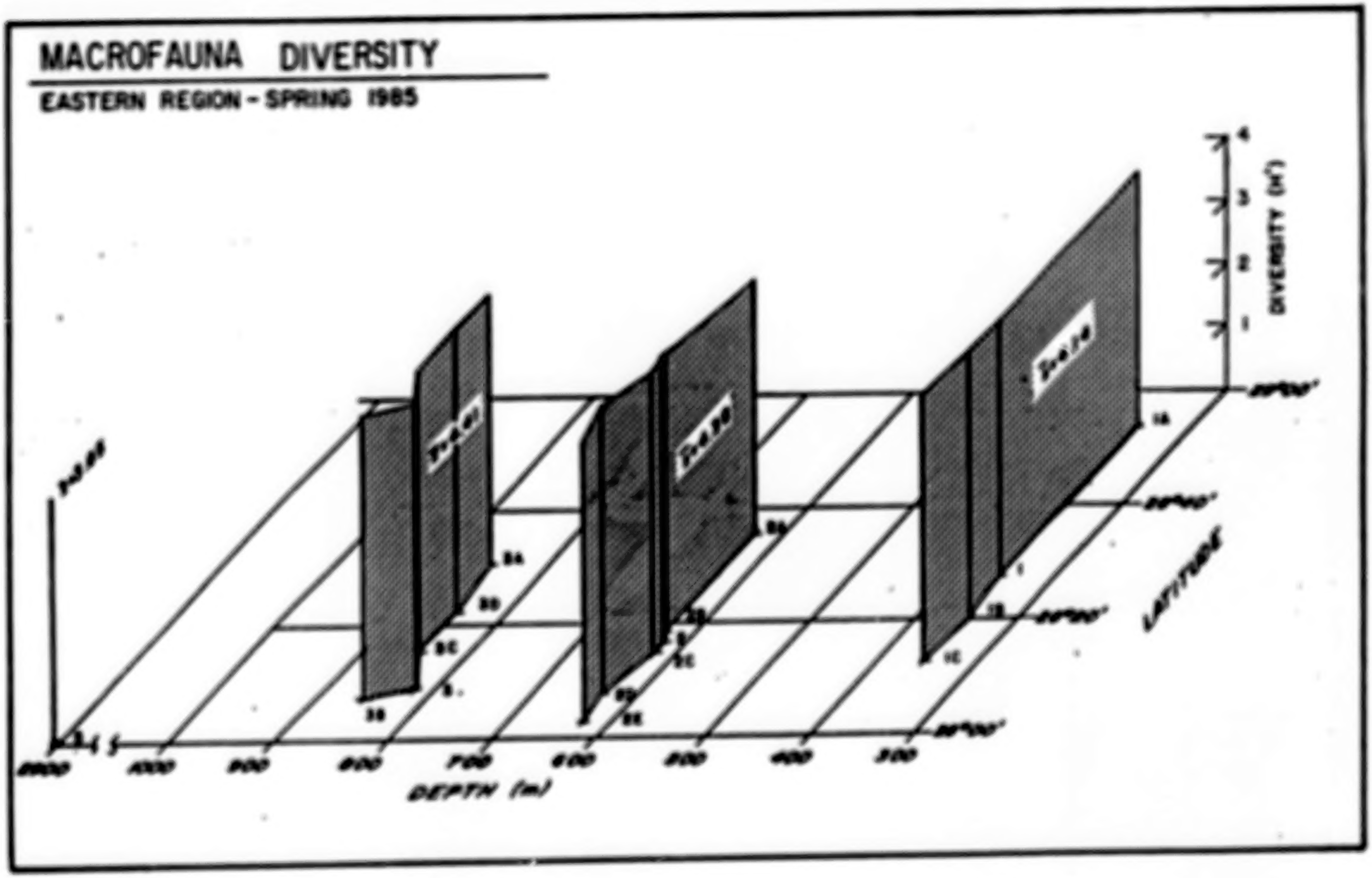

Figure 43. Comparative levels of macrofaunal diversity along selected isobaths in the Eastern Gulf of Mexico during Spring 1985.

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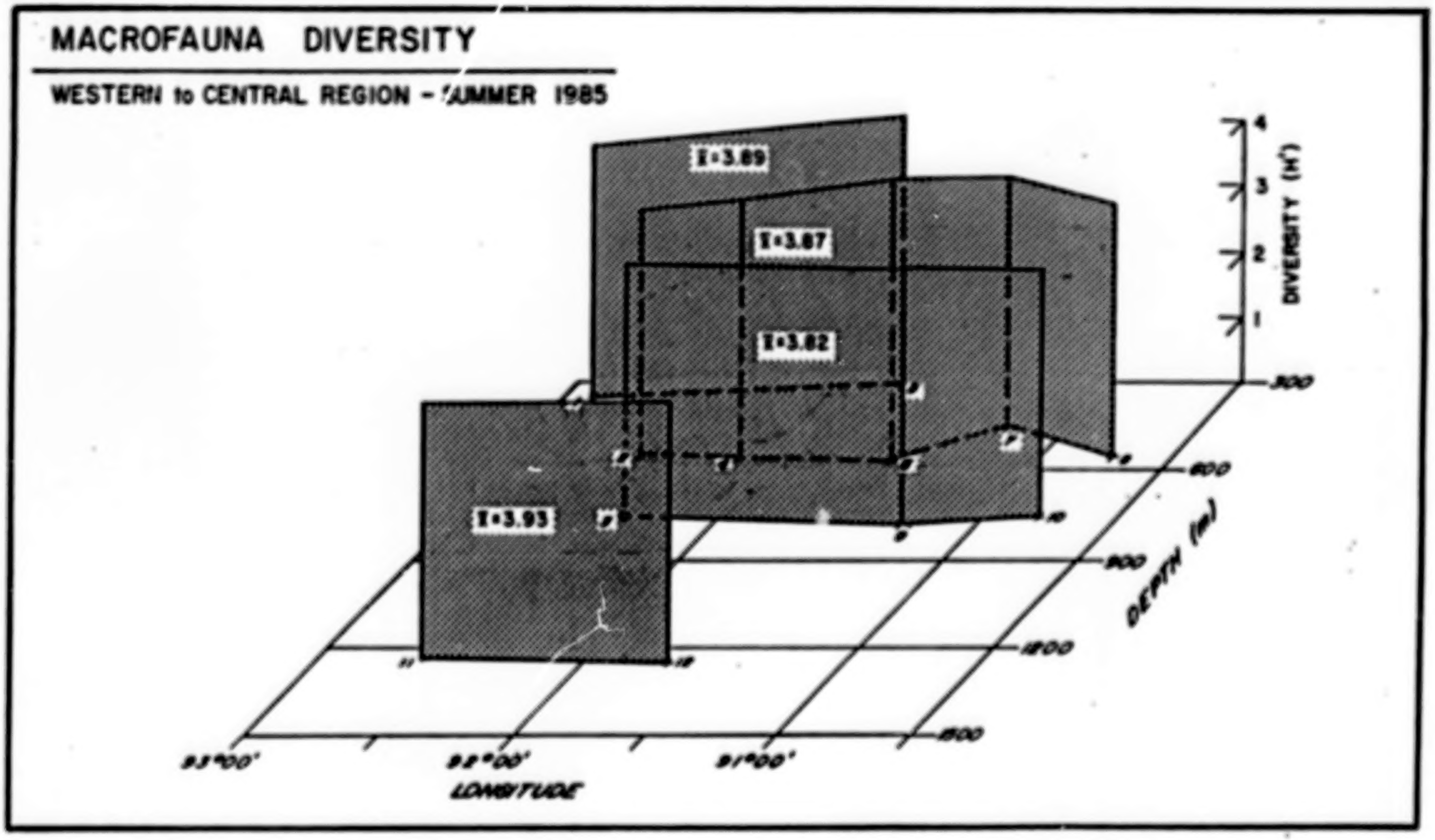

Figure 44. Comparative levels of macrofaunal diversity along isobaths between the Central and Western Gulf of Mexico sampling transects, Summer 1985.

Gastropoda, Aplacophora, Bivalvia, Scaphopoda, Acarina, Ostracoda, Copepoda, Cumacea, Tanaidacea, Isopoda, Amphipoda, Decapoda, Pogonophora/Vestimentifera, Sipuncula, Priapulida, Bryozoa, Brachiopoda, Ophiuroidea, Echinoidea, Holothuroidea, and Ascidiacea.

We shall not attempt to summarize these results herein, but refer the reader to that volume. However, a few comments are in order. Of the 18 groups for which highest and lowest total transect diversities (i.e., number of taxa at all stations on the transect) were figured, 61% had their greatest diversity at the East Transect on Cruise IV and 61% had their lowest diversities at the West Transect. Likewise, of the 26 macrofaunal groups for which mean transect densities were calculated, 54% of the groups had their highest mean transect densities at the East Transect on Cruise IV while 46% had their lowest mean densities on the West Transect. Another 31% had their lowest densities on the Central Transect on Cruise III.

4.3 MEGAFAUNA

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4.3 MEGAFAUNA

4.3.1 INTRODUCTION

The megafauna discussions in Volume II and below, are based upon the fish and invertebrate collections made by trawling. Complete listings of the catch data can be found in Volume III: Appendices, specifically Appendices C3-1 through C3-11. Life history information (e.g., length-weight) was taken for selected species, these raw data can also be found in Volume III, Appendices C4-1 through C4-26. The life history information along with food habit and distributional data were used to prepare species or life history accounts for selected megafaunal invertebrates and fishes. These are provided in Sections 4.3.4 and 4.3.5 (invertebrates and fishes, respectively) of Volume II. Collectively, these data set the stage for the comprehensive synthesis of the final year.

4.3.2 COMMUNITY STRUCTURE AND DIVERSITY

In this section we describe the relative abundance patterns of fish and invertebrates by transect (= region) and depth. Based upon previously defined lack of any definitive seasonal or annual patterns, these topics do not warrant special discussion.

4.3.2.1 Numerical Abundance by Transect

Megafaunal invertebrates, based upon data from the five cruises, were some four to five times more abundant than fishes on each transect in terms of average density:

	Number/ha		
TRANSECT:	West	Central	East
Fish	1222	620	1511
Invertebrates	5045	2621	7952
Combined	6267	3241	9465

The Central Transect was characterized by the lowest density of megafauna (3241/ha) which was some 50% lower than density observed on the Western Transect (6267/ha) and only about one-third of the density found for the Eastern Transect (9463/ha).

4.3.2.2 Numerical Abundance by Depth

The total and mean densities (number per hectare) of demersal fish and invertebrates are presented by depth intervals on the three major transects in Table 6. Note that there are six depth intervals beginning with 328-423 m and ending with 2100-2855 m on each of the three major transects. The number of stations within each depth interval are not the same in the three transects. For instance, in the case of the 328-423 m interval, there are three stations on the West and Central Transects and five on the East Transect. Hence in the case of fish on the West Transect the sum of the densities at the three stations was 476 with an average number of individuals of 159/ha. Three major points stand out very clearly: (1) the densities of the invertebrates are consistently the larger, (2) densities are highest on the Eastern Transect and lowest on the Central Transect as described above, and (3) the densities tend to drop at and below the 1550 m isobath. A similar pattern was found for many of the macrofaunal groups.

4.3.2.3 Species Diversity by Region and Depth

Species diversity (H" and number of species) of megafaunal invertebrates and fishes, by region and depth, are presented in Figures 45 through 47, and 48 through 50, respectively. For invertebrates, there were no clear trends in the diversity index by depth nor were there any apparent substantive differences in invertebrate diversity among the three regions. Using 30 species as a reference point, 80% of the collections taken on the Central Transect had fewer than 30 invertebrate species whereas only about 30% of the collections on both the Eastern and Western Transects had fewer than 30 species. At least part of this difference is attributable to more samples being taken at depths below 1250 m on the Central Transect than on either the Western or Eastern Transects. Depths

Table 6. Densities (individuals per hectare) of megafaunal invertebrates and demersal and benthopelagic fishes at six depth intervals on three major transects. (Tot. = Catch adjusted by bottom trawl and trawl size; CPE = Density/trawl haul.)

Depths 328-423 m

	Western Transect				Central Transect				Eastern Transect				
	Fish		Inverts		Fish		Inverts		Fish		Inverts		Mean
Tot.	476		897		197		345		704		2030	=	775
CPE.	159	+	299	+	66	+	115	+	141	+	406	=	198

Depths 465-750 m

	Western Transect				Central Transect				Eastern Transect				
	Fish		Inverts		Fish		Inverts		Fish		Inverts		Mean
Tot.	469		1960		175		732		347		4368		1342
CPE.	67	+	280	+	58	+	244	+	50	+	624	=	221

Depths 751-1000 m

	Western Transect				Central Transect				Eastern Transect				
	Fish		Inverts		Fish		Inverts		Fish		Inverts		Mean
Tot.	142		605		171		900		239		819		479
CPE.	47	+	202	+	34	+	180	+	40	+	117	=	103

Depths 1050-1500 m

	Western Transect				Central Transect				Eastern Transect				
	Fish		Inverts		Fish		Inverts		Fish		Inverts		Mean
Tot.	135		1541		56		273		219		715		490
CPE.	45	+	514	+	19	+	68	+	109	+	357	=	185

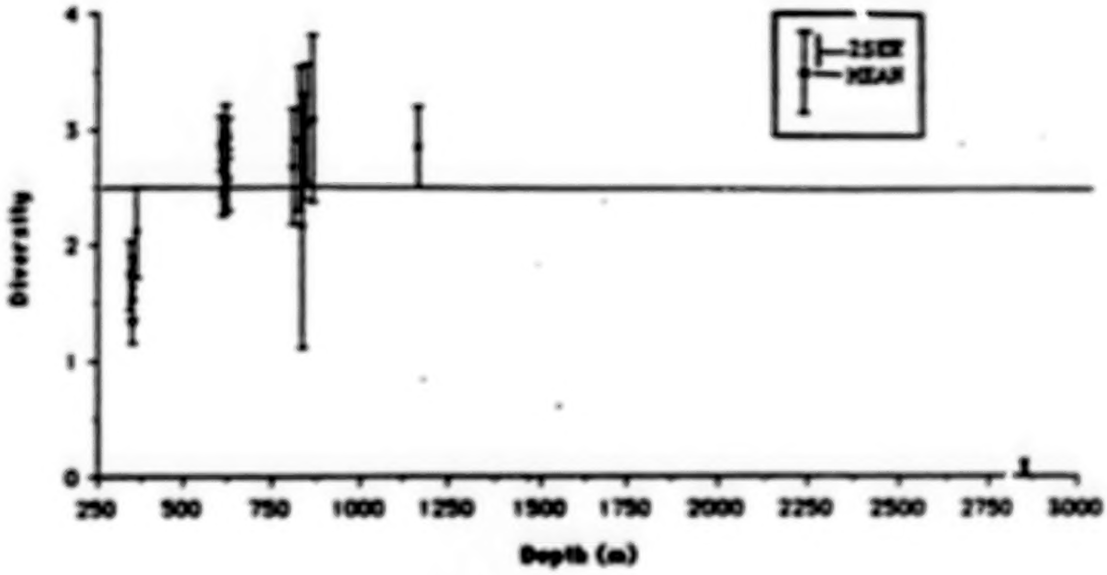
Depths 1550-2050 m

	Western Transect				Central Transect				Eastern Transect				
	Fish		Inverts		Fish		Inverts		Fish		Inverts		Mean
Tot.	0		0		11		182		0		0		97
CPE.	0		0		4	+	61		0		0	=	11

Depths 2100-2855 m

	Western Transect				Central Transect				Eastern Transect				
	Fish		Inverts		Fish		Inverts		Fish		Inverts		Mean
Tot.	0		42		10		189		2		20		44
CPE.	0		21	+	3	+	63		0		0	=	15

Diversity of Invertebrate Species on the Eastern Transect



Number of Invertebrate Species on the Eastern Transect

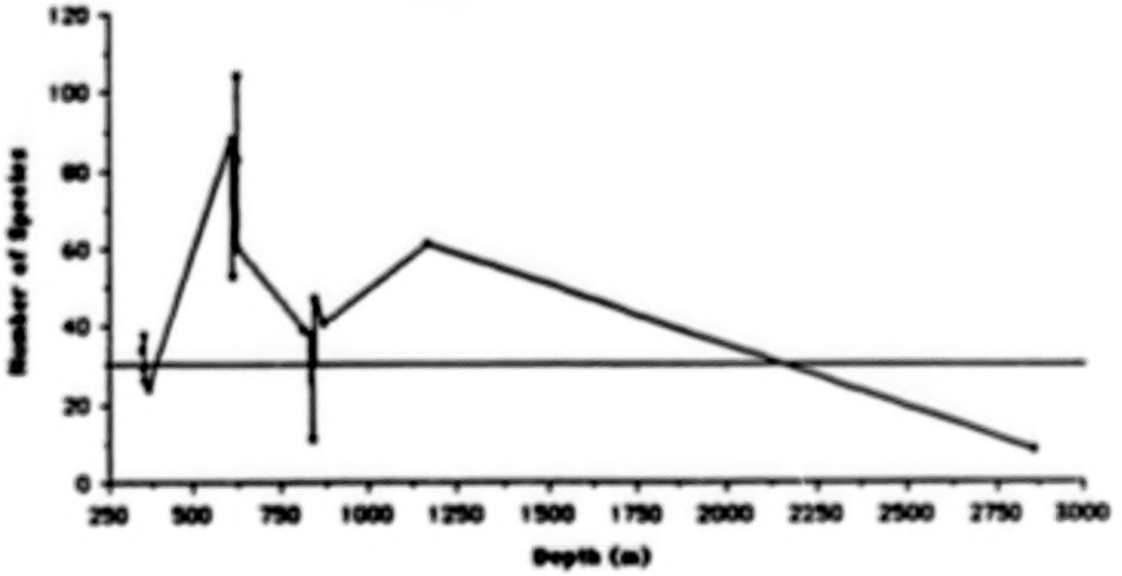
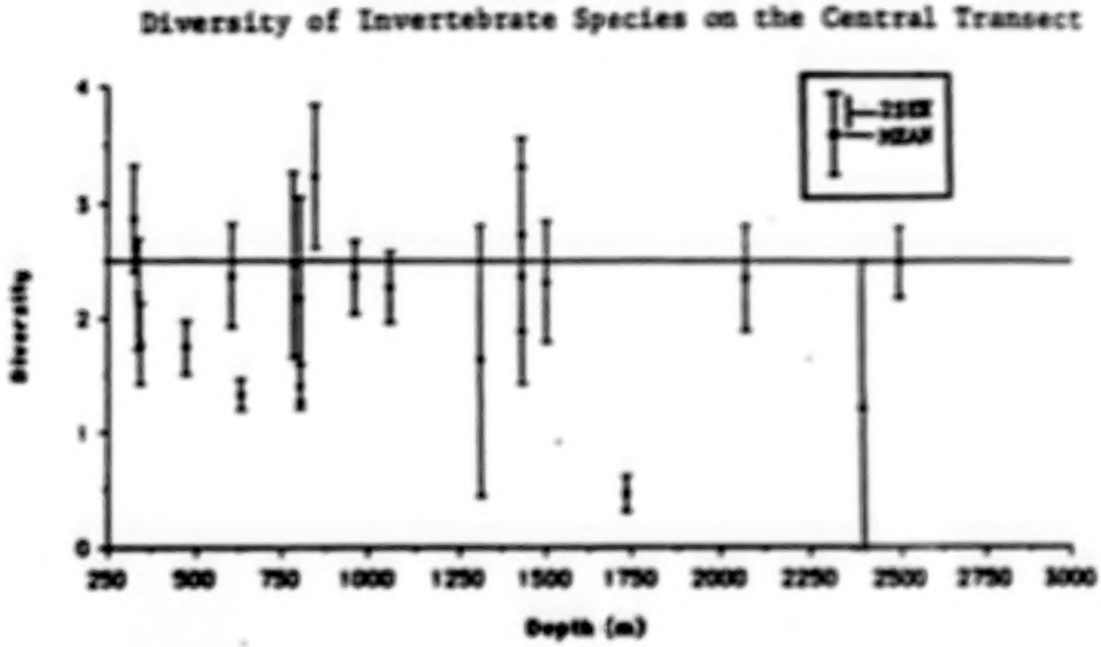


Figure 45. Species diversity and number of species of megafauna invertebrates for the Eastern Transect, Cruises I-V.


Diversity of Invertebrate Species on the Central Transect

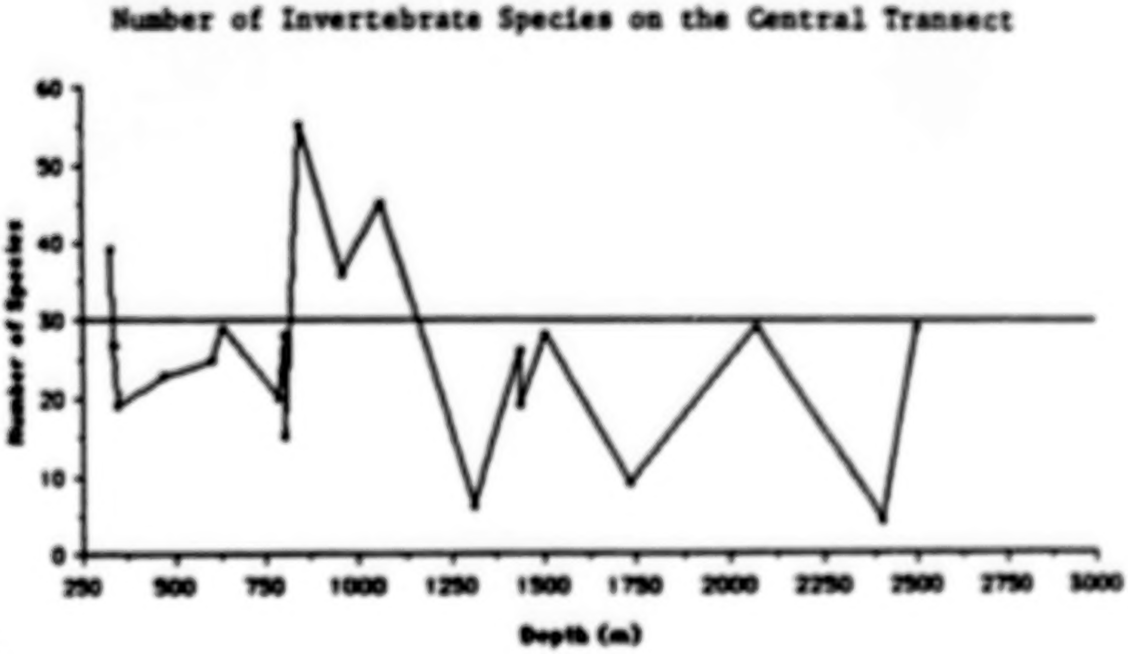
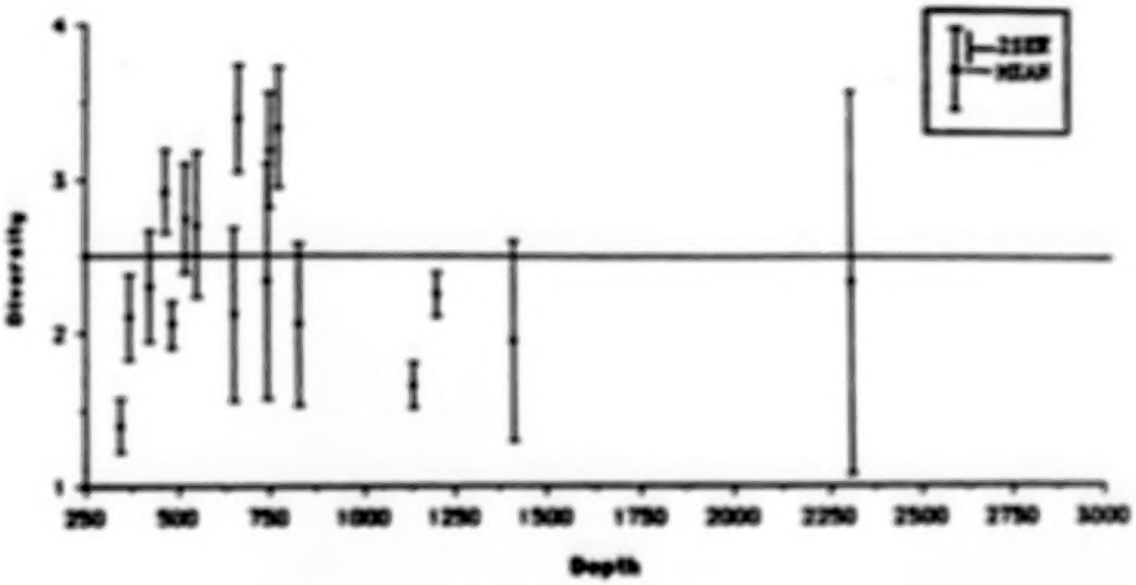
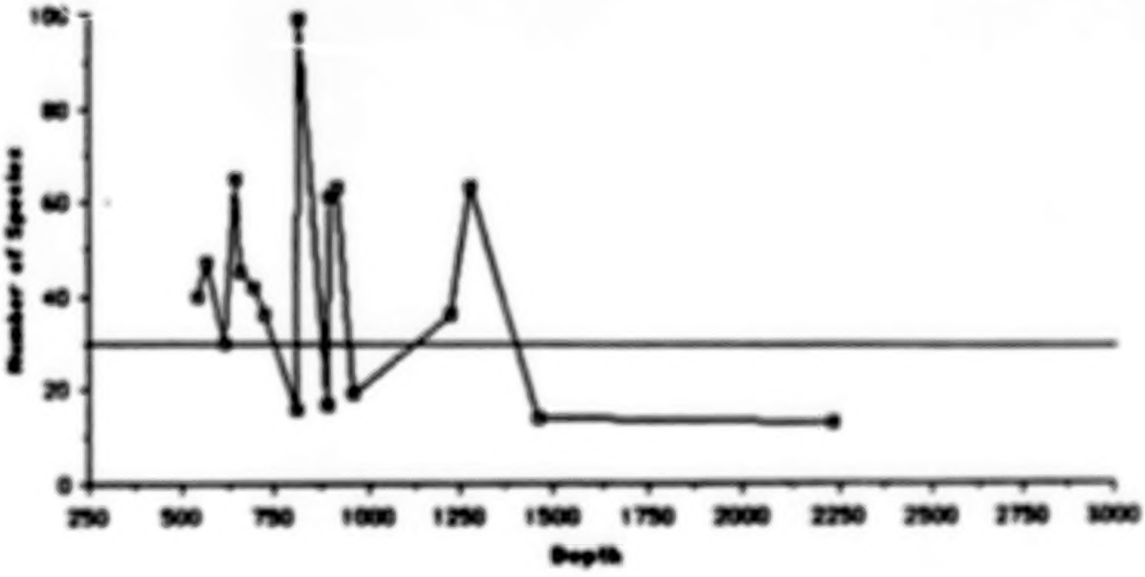

Number of Invertebrate Species on the Central Transect

Figure 46. Species diversity and number of species of megafauna invertebrates for the Central Transect, Crusies I-V.



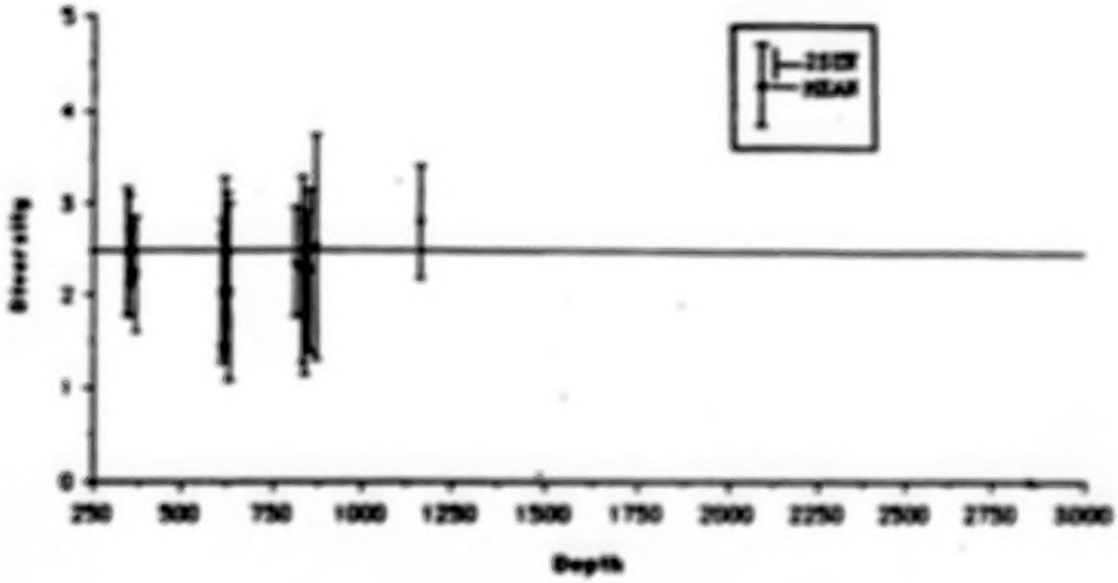
Diversity of Invertebrate Species on the Western Transect



Number of Invertebrate Species on the Western Transect

Figure 47. Species diversity and number of species of megafauna invertebrates for the Western Transect, Cruises I-V.

Diversity of Fish Species on the Eastern Transect



Number of Fish Species on the Eastern Transect

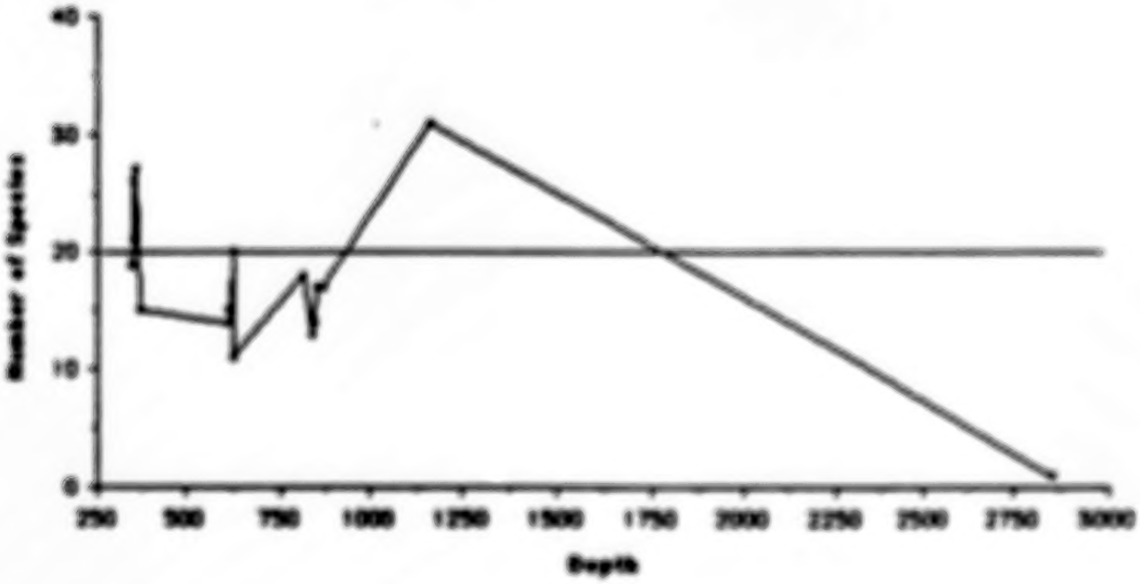
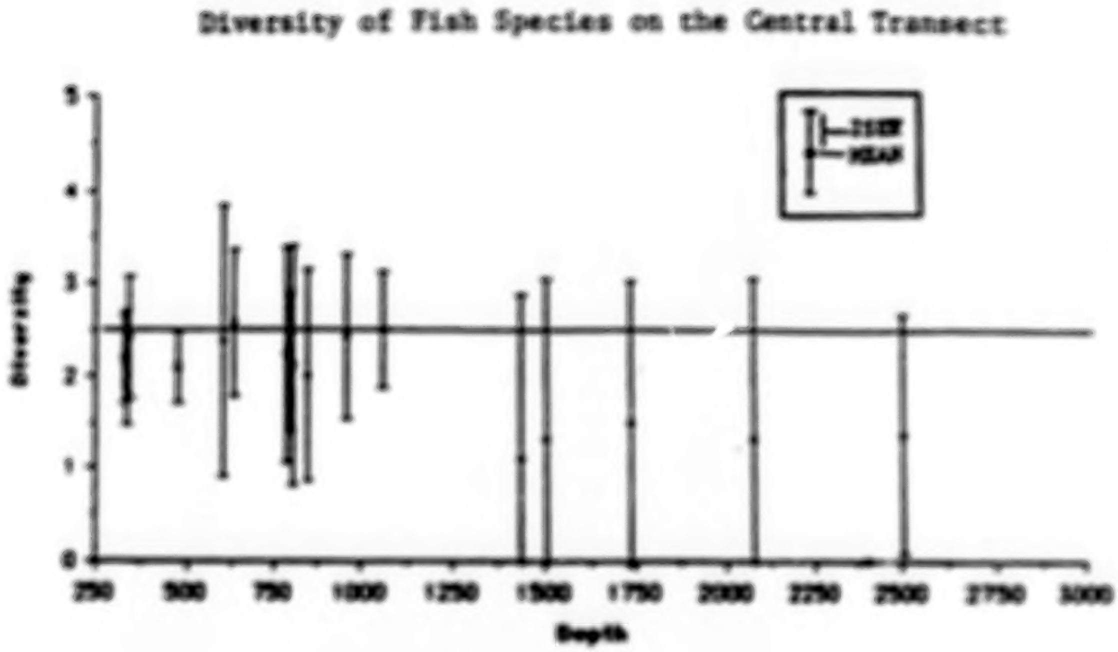
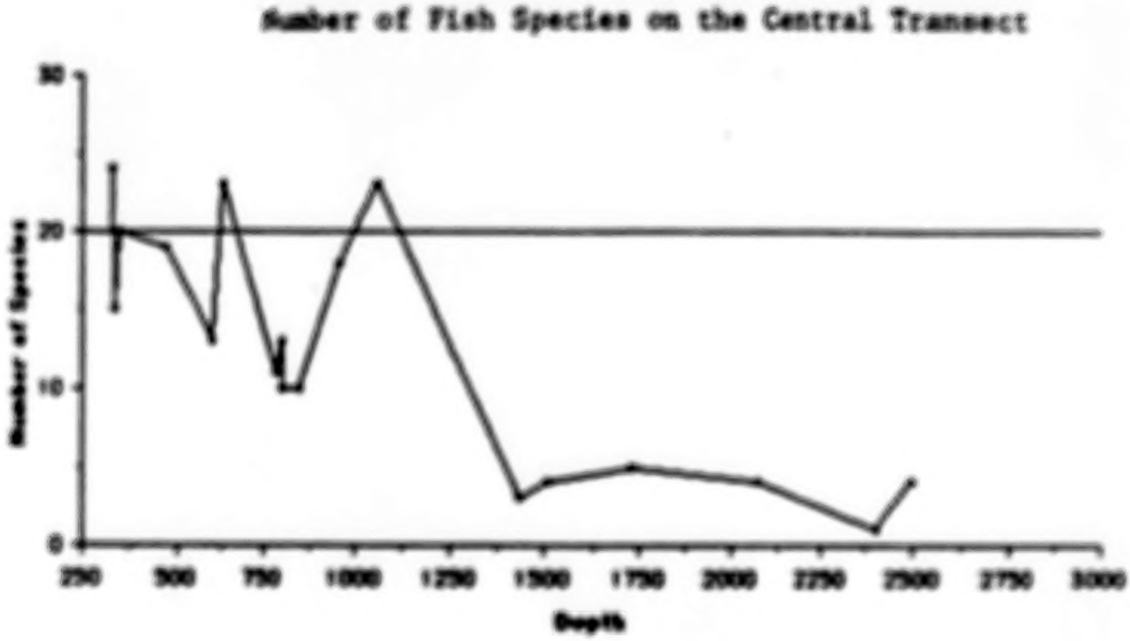


Figure 48. Species diversity and number of species of fishes for the Eastern Transect, Cruises I-V.

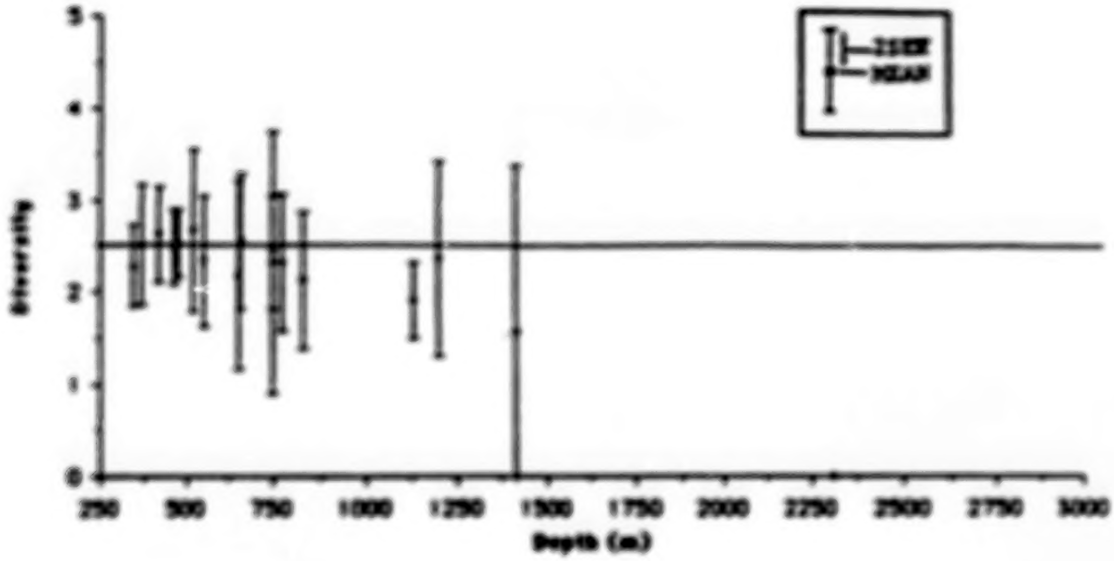


Diversity of Fish Species on the Central Transect



Number of Fish Species on the Central Transect

Figure 49. Species diversity and number of species of fishes for the Central Transect, Cruises I-V.


Diversity of Fish Species on the Western Transect

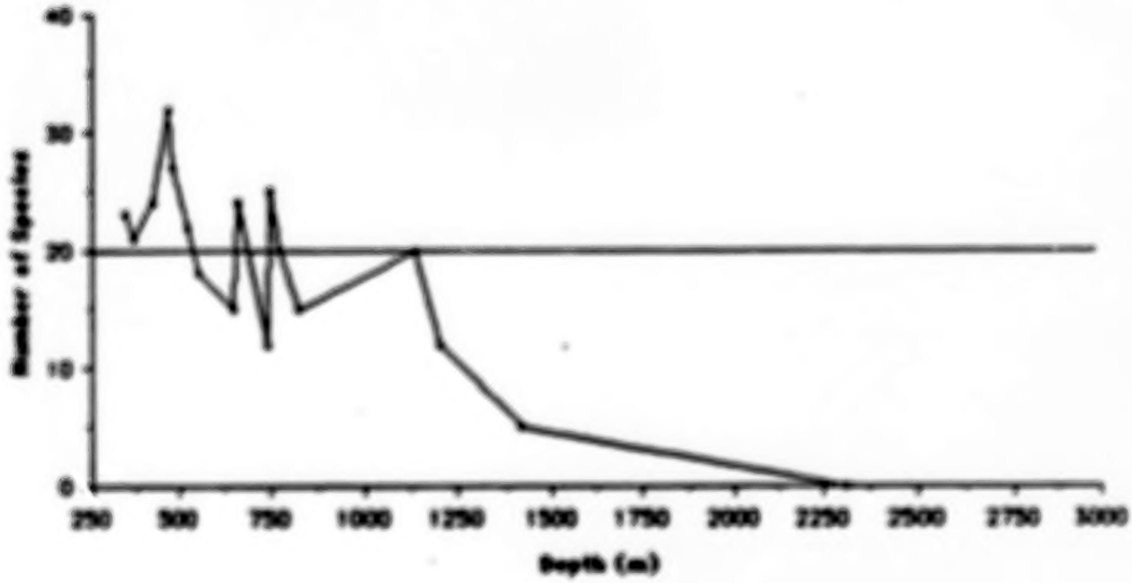

Number of Fish Species on the Western Transect

Figure 30. Species diversity and number of species of fishes for the Western Transect, Cruises I-V.

below 1250 m appeared characterized by fewer species than shallower depths.

Examination of the fish diversity data suggests a decline in diversity as well as number of species at depths exceeding 1250 m (Figs. 48 through 50). There were no obvious differences in fish diversity among the three regions.

4.3.2.4 Bathymetric Zonation of Megafauna

The results in the first two Annual Reports emphasized vertical zonation discussions drawing upon data from Cruises I through III. The preliminary conclusion was that a case could be made supporting the zonation scheme proposed in the TerEco baseline (Pequegnat 1983).

Cluster Analyses

The data derived from Cruises IV and V have provided support for a conception presented in earlier reports as to how faunal assemblages are distributed over the upper and middle portions of the continental slope. For the past several years, oceanographers have differed as to whether or not benthic animals are arrayed on the slope in discernible vertical bands or zones. Although there is general agreement that the composition of the faunal assemblages changes with changes in depth, there are those who believe that the so-called zones are artifacts of sampling, i.e., that the limits of the zones are wholly related to the depths at which sampling was done. One must point out, however, that Haedrich et al. (1975, 1980) identified four faunal zones on the U.S. North Atlantic slope, and in 1983 Hecker et al. in an MMS report designated five faunal zones on the same slope. In the same year, Pequegnat (1983), again in an MMS report, identified five major zones on the slope and rise of the Gulf of Mexico. More recently the 1986 report on the MMS study of the U.S. North Atlantic benthic fauna carried out by Batelle, Lamont-Doherty, and Woods Hole contains descriptions of six faunal zones on the slope. These findings, which are based upon both classification and ordination analyses, reveal that the replacement of species with depth is not uniform. In other words the "rate of replacement" is not the same on all vertical aspects of the slope. Accordingly, one may regard zones as being large areas of relatively small faunal change with depth that are separated by smaller areas where the rate of exchange of species is high. These separations have been referred to as "breaks", but this is not a wholly acceptable term because it tends to ignore the fact that few or many taxa may be shared between neighboring zones.

It was reasoned that if this concept of zones is correct, then there should be far fewer exchanges of faunal species sampling along isobaths than sampling up or down the slope. And, by the same token, sampling along successively deeper isobaths should show increasing degrees of difference when compared with the samples from the shallowest isobath. Thus, it was decided to trawl isobathymetrically on consecutively deeper isobaths along two transects, namely, the East Transect during Cruise IV (Fig. 51) and the West-Central Transect during Cruise V, as shown in Figure 52. Note that Stations E1, 1a, 1b, and 1c are arrayed slightly above or below one isobath at a depth of about 350 m, whereas 2, 2a, etc., and 3, 3a, 3b, etc. are on isobaths having depths of about 625 and 840 m, respectively. Somewhat the same depth relationships were established on the West-Central Transect but the trawling tended to stray off the isobath to a greater degree than on the East Transect (Fig. 52). In particular note the large depth ranges at Stations WC6 and WC11.

The NESS similarity measure (Grassle and Smith 1976) was used to analyze data derived from Cruises IV and V. Figure 53 shows the dendrogram that results from the application of NESS to all of the megafaunal invertebrates taken during Cruise IV. There is a clear separation of the faunal clusters from one isobath to another. Moreover, the E2 and E3 series of stations are more closely related to one another than to the E1 series. The separation of Station E2E from the others on the isobathresults from the fact that it lacked a few species and had others in reduced numbers as compared with other stations on the isobath. This gave it a pattern that resembled those more typical of the E3 depth series. Essentially the same major clusters occur when the fish data are analyzed (Fig. 54), but there are some differences in station pairings. Note, however, that in the E1 series of four stations that E1, 1B, and 1C are closely related and E1A is the outlier in both figures. In the E2 series Stations E2B, 2C, and 2D are clustered together with E2 as an

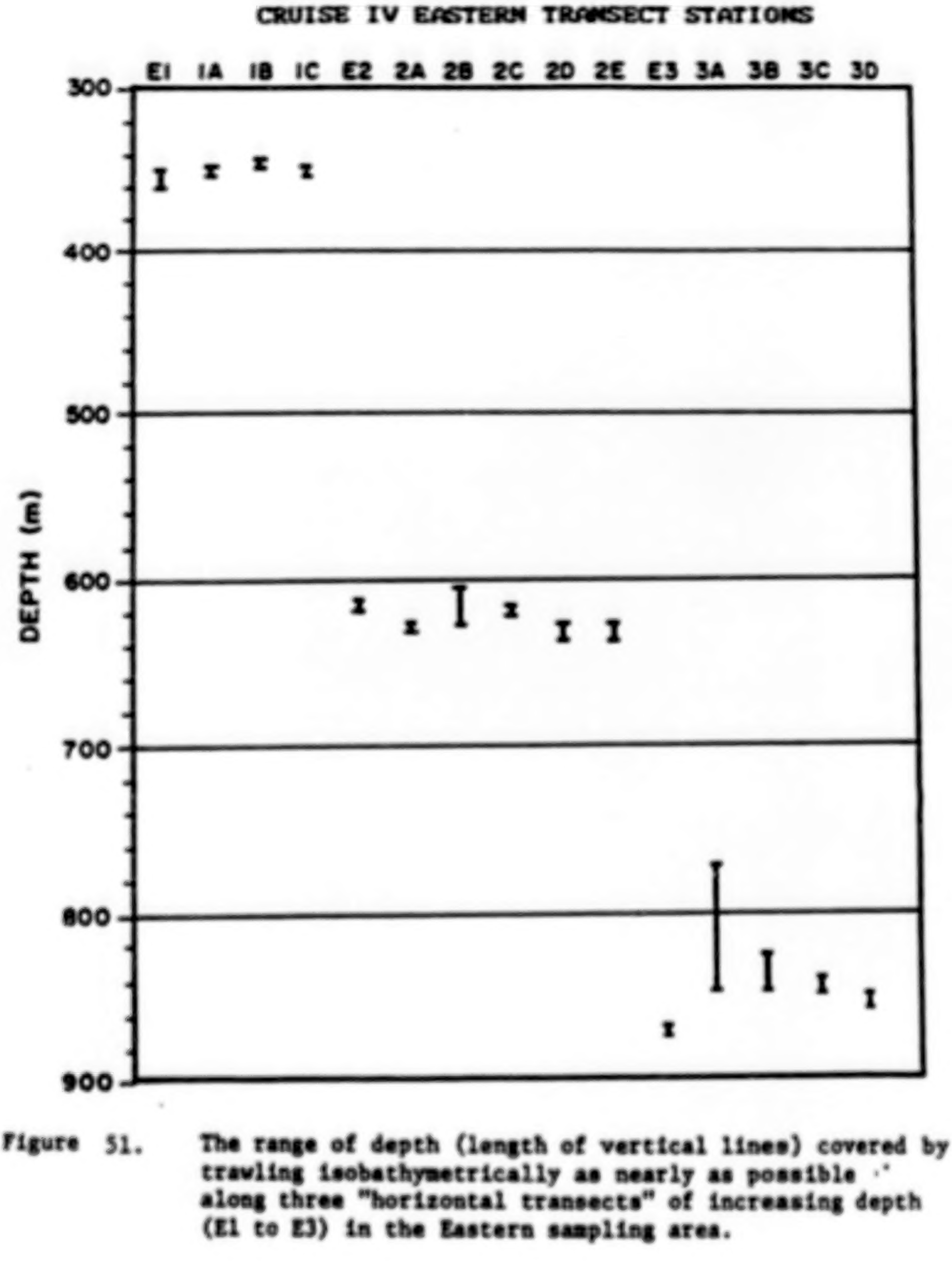


Figure 51. The range of depth (length of vertical lines) covered by trawling isobathymetrically as nearly as possible along three "horizontal transects" of increasing depth (E1 to E3) in the Eastern sampling area.

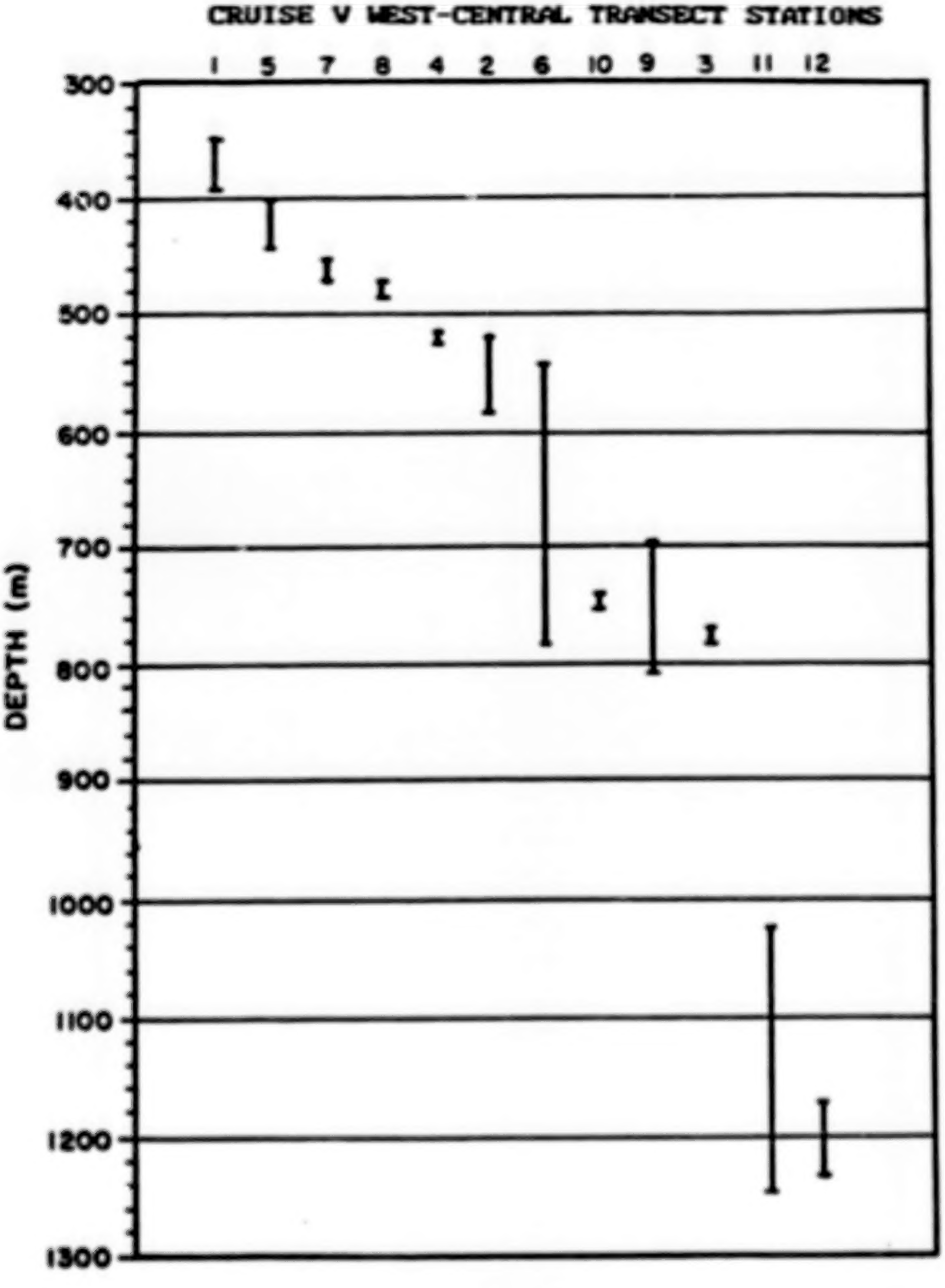


Figure 52. The range of depth covered at individual stations by trawling isobathymetrically as nearly as possible along three "horizontal transects" of increasing depth in the West-Central sampling area.

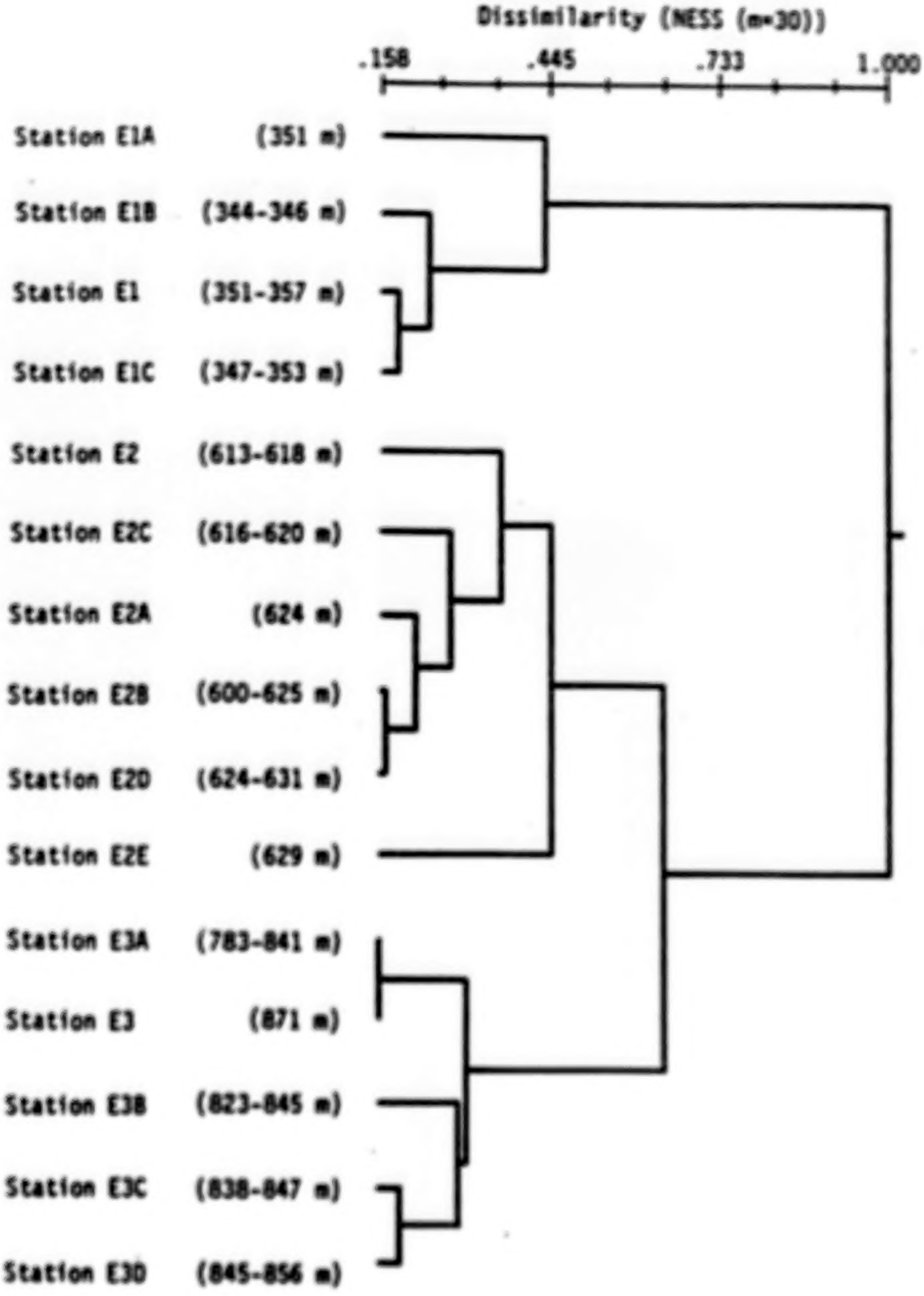


Figure 53. All invertebrates taken by trawl from the 15 stations of Cruise IV on the Eastern Transect clustered by NESS at 30 individuals. Similarity values between pairs of stations equal the reciprocal of the values given at the top of the figure. The major isobathic clusters are easily separated. Outlier stations such as E1A result less from depth than from sampling.

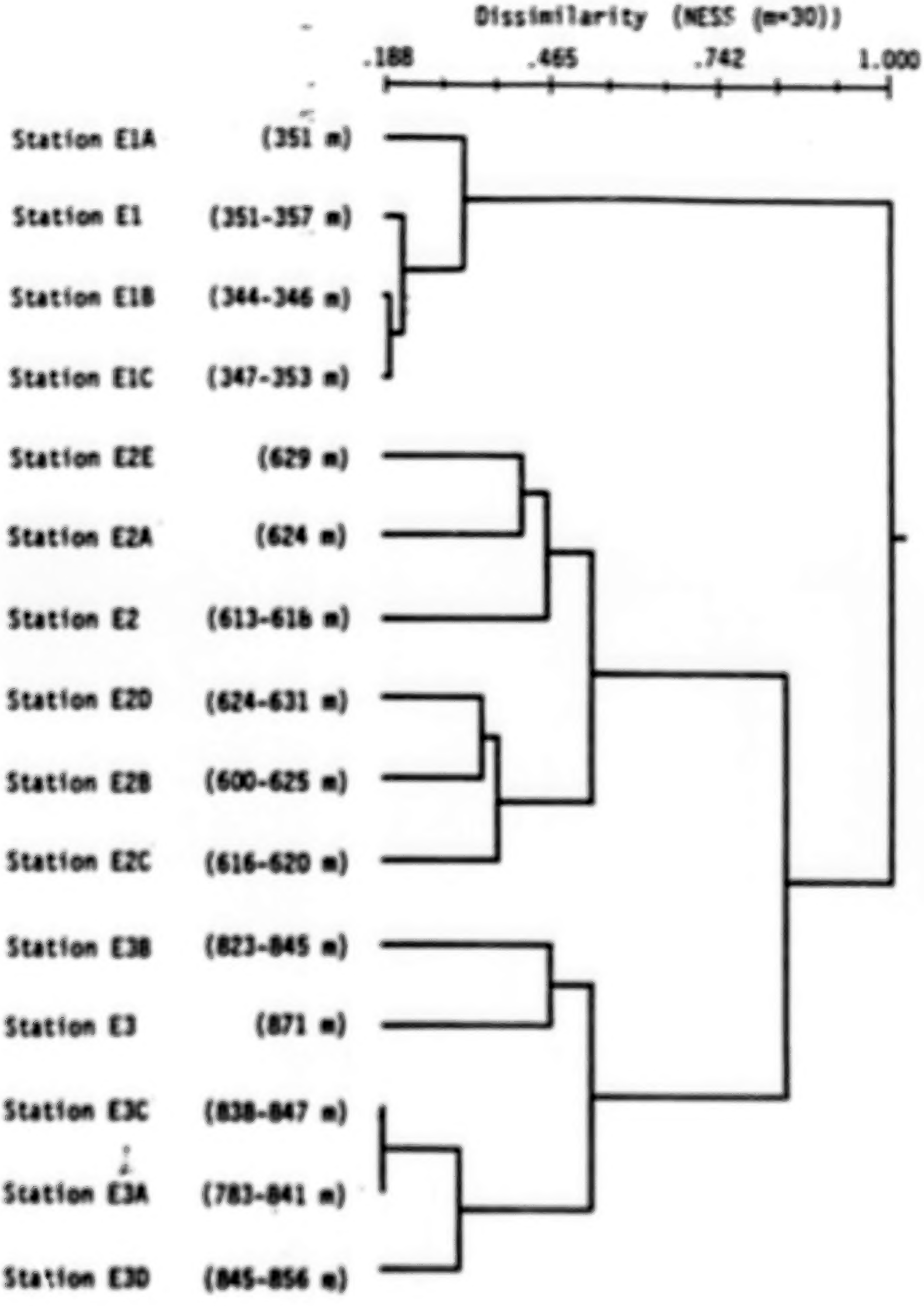


Figure 54. All fishes taken by trawl from the 15 stations of Cruise IV on the Eastern Transect clustered by NESS at 30 individuals. Comparison with invertebrate clusters in Figure 53 shows a high level of similarity.

outlier in both figures. The E3 series of five stations is much more tightly clustered for invertebrates than fishes and the pairings do differ except that Stations E3A and E3C are tightly clustered in both, although with different partners.

The dendrograms (NESS) for Cruise V invertebrates and fishes in the West-Central region, as shown in Figures 55 and 56, again show a tendency toward isobathic clustering with two major clusters, each of which is subdivided into two. Reference to Figure 1 (map of stations) and Figure 52 shows that the trawling was not carried out as effectively here as on Cruise IV. Stations are closely clustered where the range between the shallowest and deepest parts of the sampling was 70 m or less. In the case of WC6, the range was over 240 m. This depth difference will not always make much difference unless it crosses a zone of species flux. The clusters derived from the invertebrate and fish data are remarkably similar. Note, for example, that in both Figures 55 and 56 Stations WC1 and WC5 are paired and Stations WC2, 4, 7, and 8 form a cluster, as do WC3 and 9 and WC11 and 12, and in both WC10 is an outlier. It is only Station WC6 that shifts its position, clustering with the deeper invertebrate stations and the shallower fish stations. This reflects the fact that on the West-Central Transect invertebrates are more abundant at deeper stations and fishes at shallower stations. Thus, it would appear that during the vertical transect of 240 m (from 543 to 783 m) in the case of trawling at Station WC6, relatively more fishes were taken at shallow depths and more invertebrates during the deeper part of the haul. This suggests that a critical zonal change occurs somewhere between 540 and 780 m depth.

NESS (Normalized Expected Species Shared) analysis was applied to all of the megafaunal invertebrates taken by trawl during Cruise III on the Central Transect, and Cruises IV and V on the East and West-Central Transects (Fig. 57). There is very evident isobathic clustering, but Stations C9 and C10 stand apart. Reference to the cruise log for Cruise III revealed that in both cases the trawl was filled with a huge mud lump that prevented proper sampling. In spite of the inclusion in the NESS of some stations where the trawling was not successful, there are some reasonably good clustering with possible zonal separations. Stations C5 and C11 tend to reflect the Mesoabyssal. Stations WC1, E1B, E1C, E1, E1A,

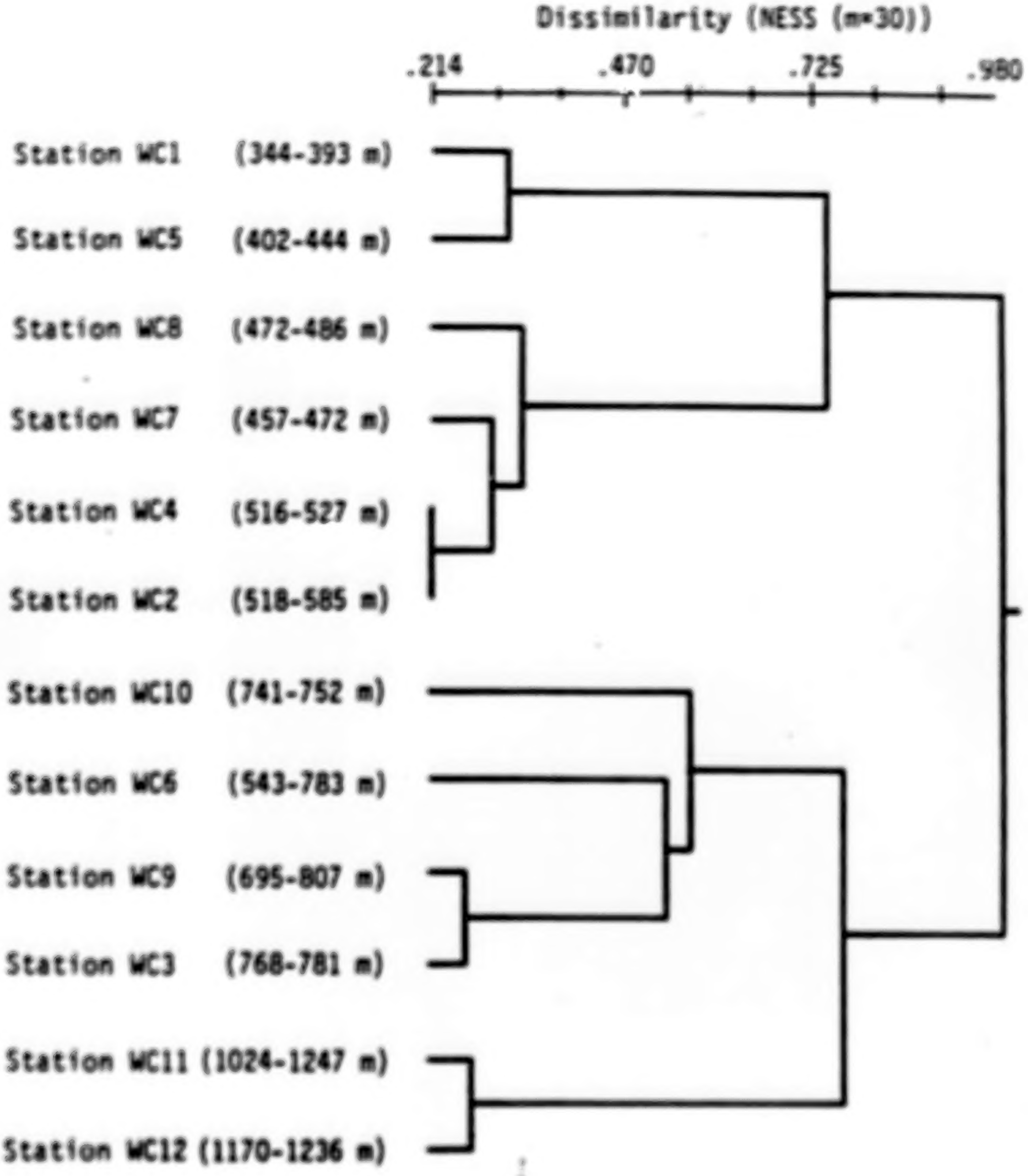


Figure 55. All invertebrates taken by trawl from the 12 stations of Cruise V clustered by NESS at 30 individuals.

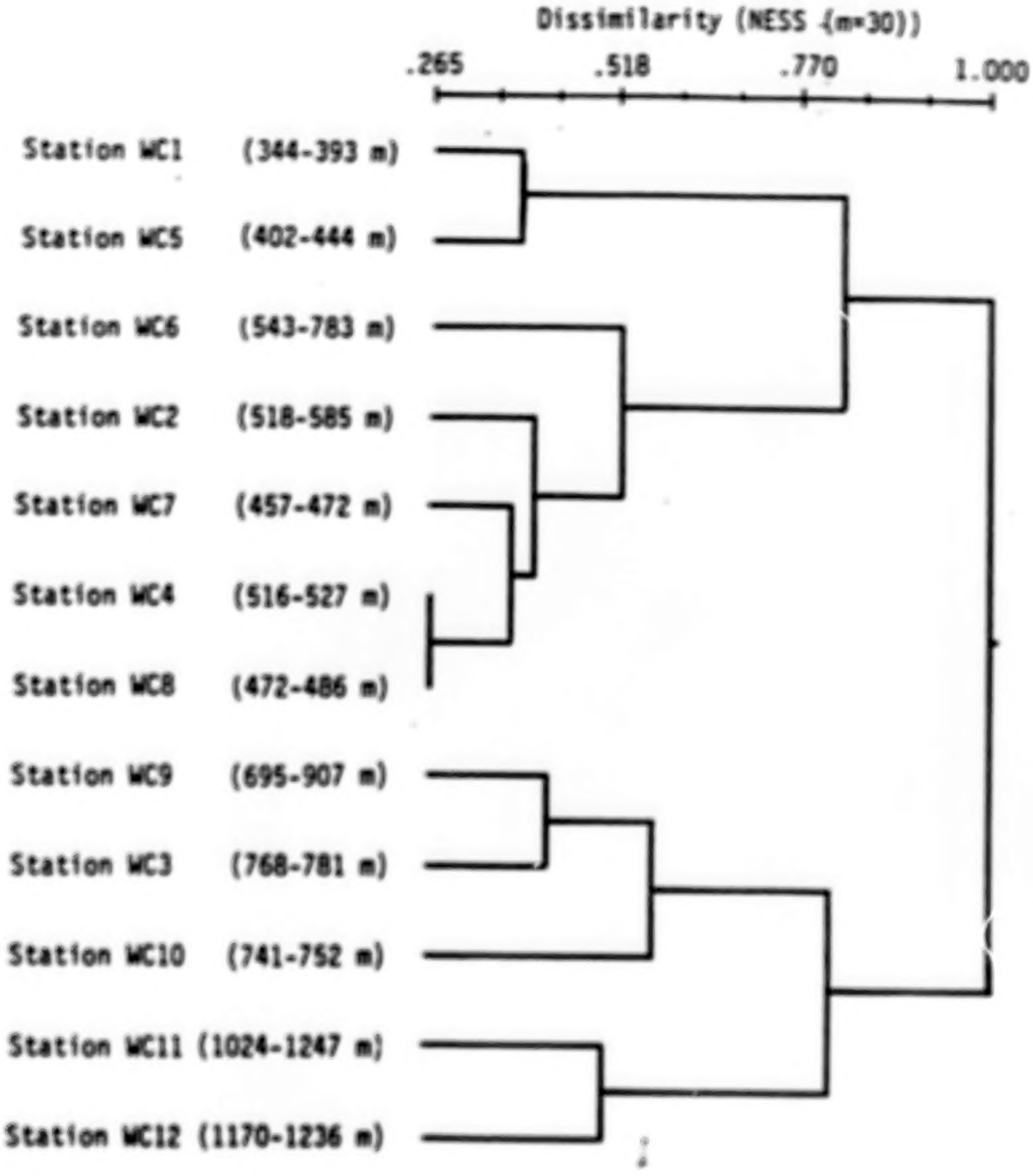


Figure 56. All fishes taken by trawl from the 12 stations of Cruise V clustered by NESS at 30 individuals. Comparison with the dendrogram of Figure 55 shows that WC6 is the only station that shifts position between the two major branches. Otherwise note WC1 and 5, and WC11 and 12, etc. are very similar.

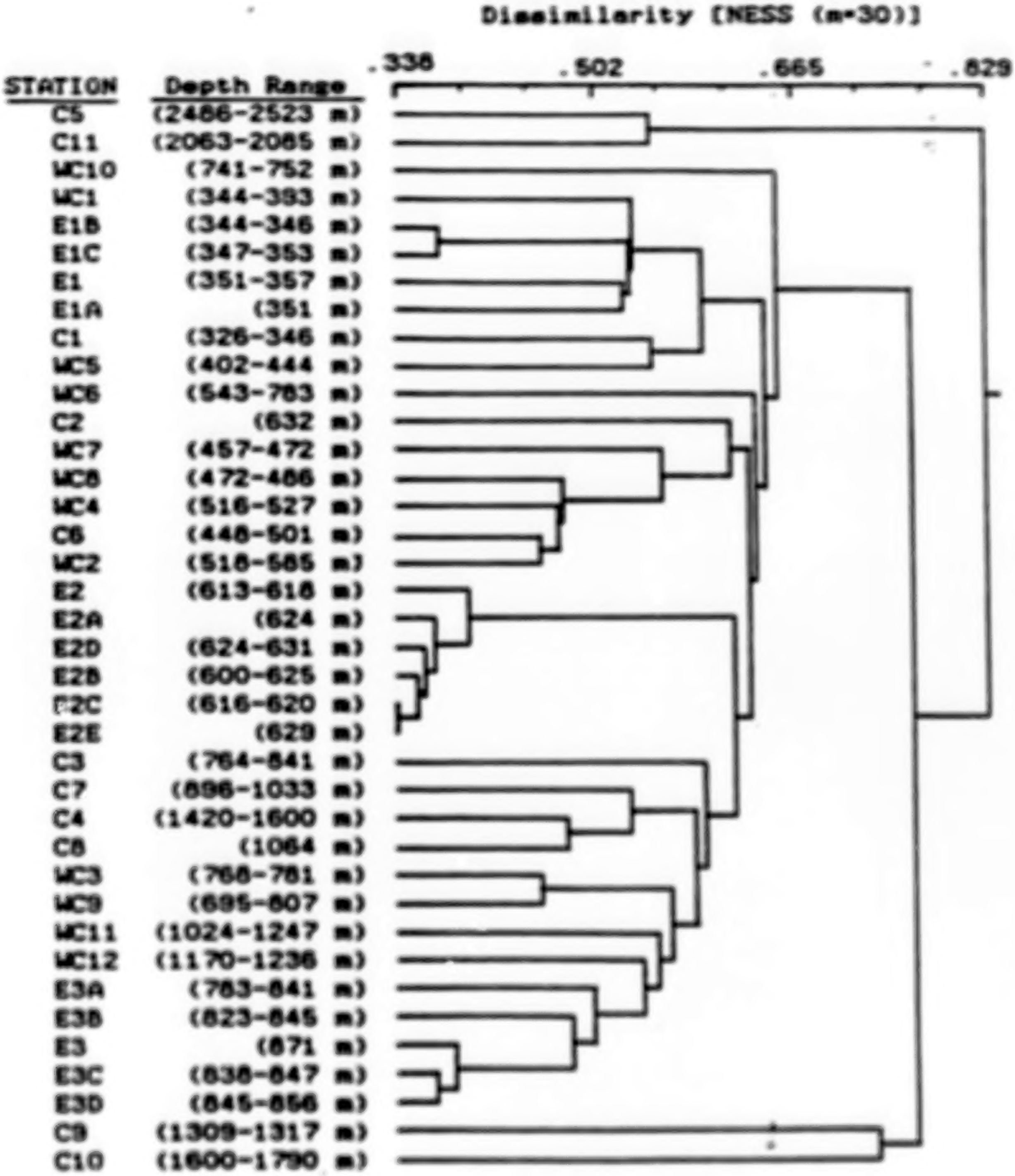


Figure 57. All invertebrates from Cruises III (Central Transect), IV (East Transect), and V (West-Central Transect).

C1, and WC5 compare well with the Shelf-Slope Transition. Most of the rest of the stations appear to be horizons of the Archibenthal Zone with the exception of Stations C4, C8, WC11, and WC12, which are very likely Upper Abyssal, as their species lists also demonstrate.

Chi-Square Analyses

As a means of detecting faunal boundaries, we utilized the chi-squared analysis method devised by Backus et al. (1965) and employed more recently by Gage (1986) in examining bathymetric zonation of the benthic fauna in the Rockall Trough south of the Wyville Thomson Ridge. In essence the method uses presence/absence data to plot the distribution of the sum of first-plus-last captures at between-station intervals on a transect having a gradient of increasing depth. If indeed the zonal concept is an acceptable way of describing bathymetric distribution, where areas of faunal homogeneity are separated by narrow regions of species change, then the occurrence of upper and lower limits should occur concurrently more frequently than expected on the basis of chance. In the present project comparisons were made between expected values for collection intervals and those actually observed using the chi-square test and obtaining probability levels. The chi-squared values, which can be thought of as indices of faunal change for each depth interval, are then plotted against depth on the abcissa. Peaks in the graph mark depth intervals of maxima in the rate of faunal change. Valleys on the graph are interpreted as being relatively homogeneous, a fact that our isobathymetric sampling tended to demonstrate.

The chi-squared analysis of the distribution of fish species together with species recruitment curves are shown in Figures 58 through 63. All of the peaks above the alpha line are significant and indicate depth intervals of high species flux. In other words, they mark the depth-location of boundaries between zones. The valleys on the other hand position the zones where the species composition of the slope is uniform. On the Central Transect there are strong peaks at depths around 450-550 m, 675-750 m, 1000 m, and 2200 m (Fig. 59). Those are close to those designated as faunal breaks for the northern Gulf of Mexico by Pequegnat (1983). Note the corresponding upsweeps in species numbers in the

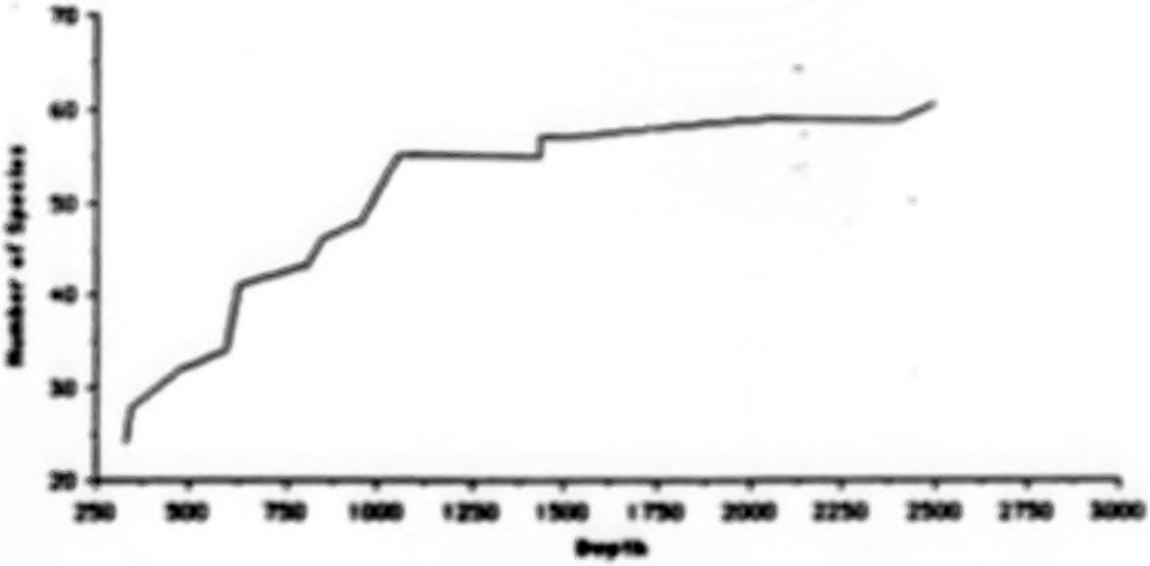


Figure 58. Species recruitment curve for fish species taken at all stations on the Central Transect.

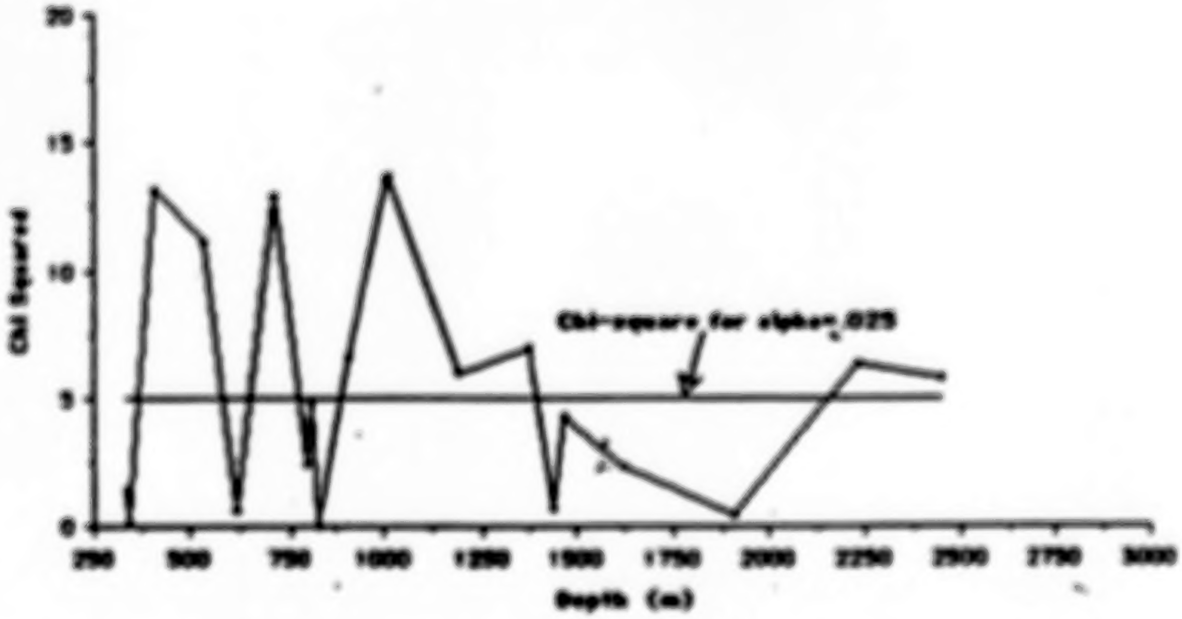


Figure 59. Chi-squared values for fish species taken on the Central Transect. Peaks above alpha line are depth intervals of high rate of species change.

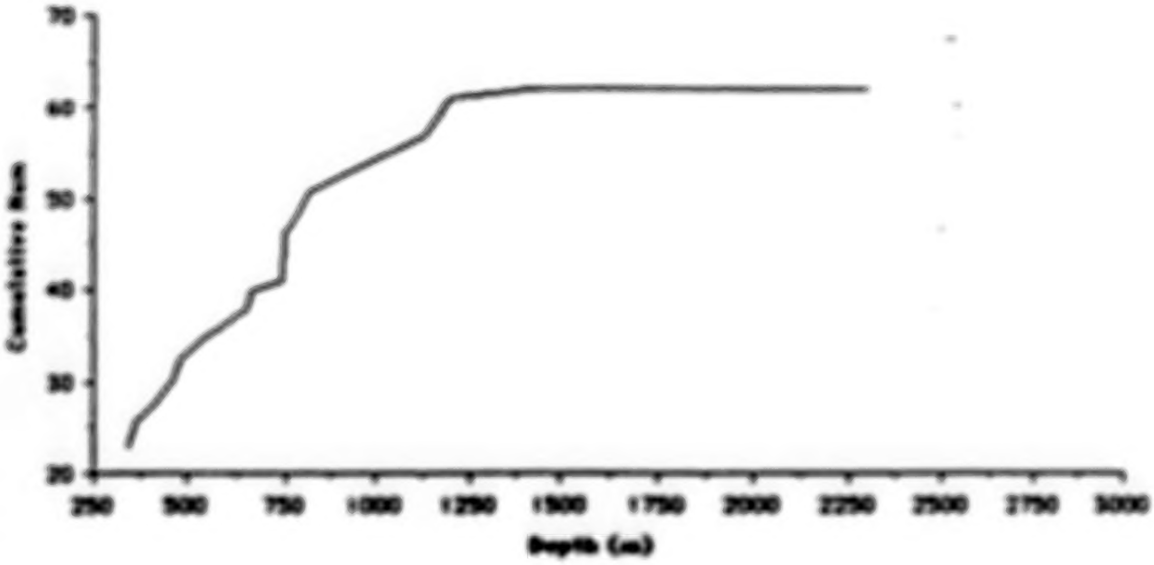


Figure 60. Species recruitment curve for fish species trawled on the Western Transect.

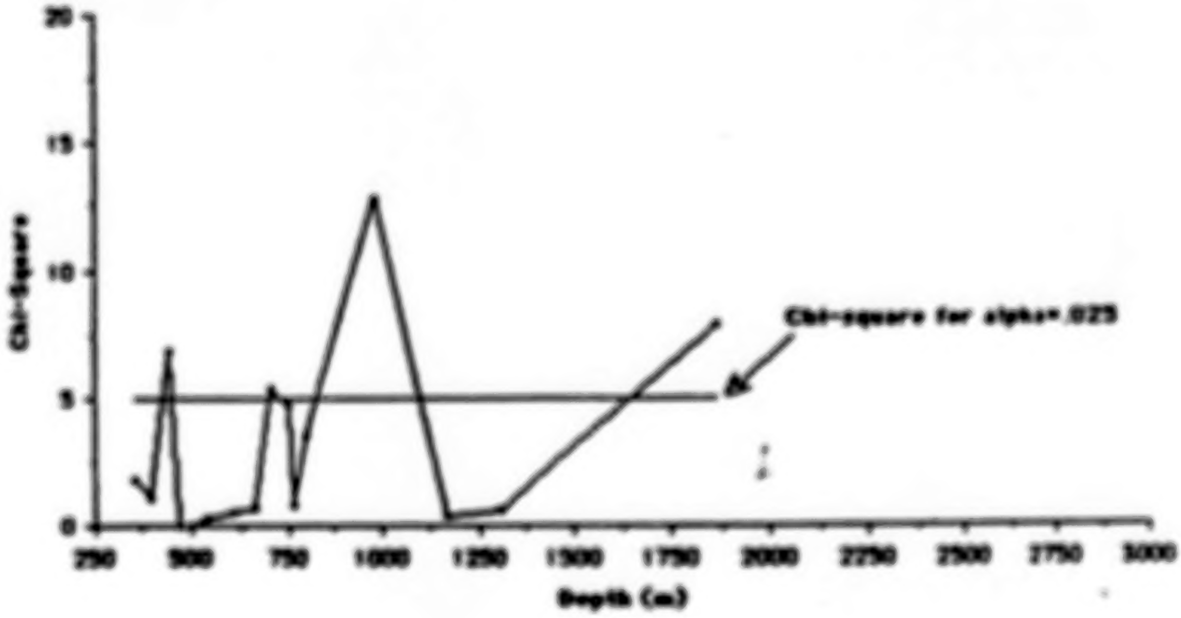


Figure 61. Chi-squared values for fish species taken on the Western Transect.

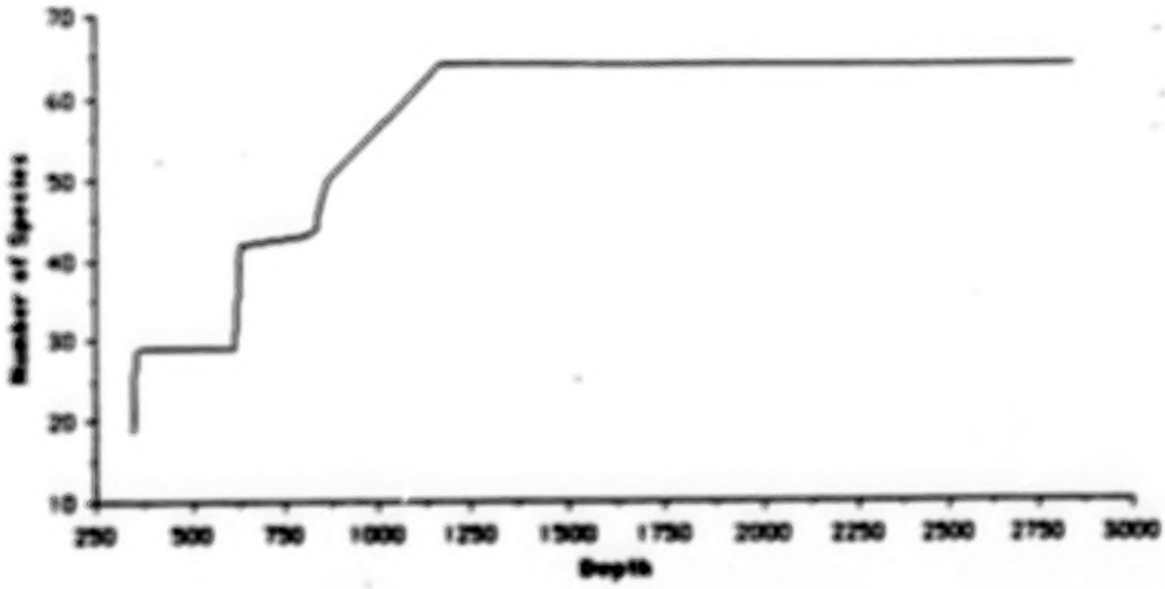


Figure 62. Species recruitment curve for fish species trawled on the Eastern Transect.

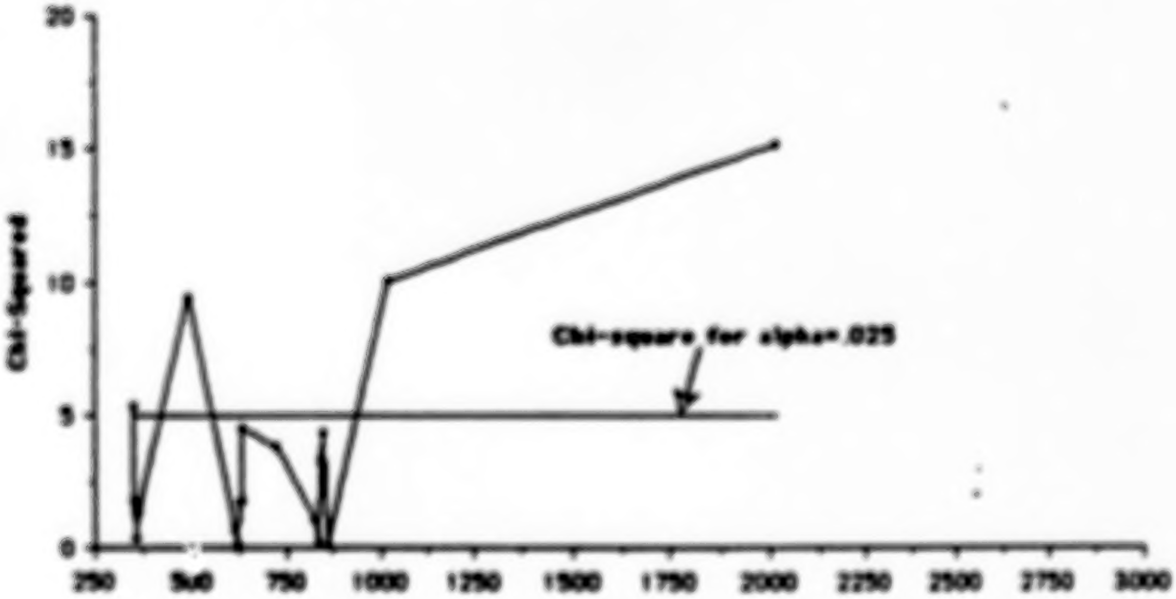


Figure 63. Chi-squared values for fish species taken on the Eastern Transect.

recruitment curve in Figure 58. Chi-squared and species recruitment values for fishes on the Western Transect are shown in Figures 60 and 61. Again there are peaks around 450, 700, and 1000 m, and deeper, but the latter depths are not reliable because of the limited amount of sampling at deeper depths on this transect. For the Eastern Transect, peaks occur around 300, 500, 1000 and 2000 m (Fig. 63); again, little sampling occurred at depths at or greater than 1000 m.

Results for the invertebrate chi-square analysis are presented in Figures 64 through 69. The chi-squared analysis of invertebrate species on the Central and Western Transects differs from that for fishes on these transects in that only one major peak is found on each transect. On the Central Transect the major peak lies between 850 and 1050 m depth, with minor peaks at 650-700, 1350, and one beginning at 2250 m (Fig. 65). The recruitment curve shows a weak increase at 625-650, a strong one at 775 m, one beginning at 1000 m, and others at 1400 and 2400 m (Fig. 64).

The invertebrate chi-squared values on the Western Transect are much more clearly defined than those on the Central Transect at depths less than 1300 m (Fig. 67). The first peak is at 450 m, followed by a very strong one between 700 and 750 m, a smaller one at 1000 m and another near 1300 m. The very limited sampling at depths greater than 1250 or so m on this transect make further analysis unreliable. The species recruitment curve has very pronounced increases that aid one in interpreting the chi-squared values (Fig. 66).

For the Eastern Transect, the major faunal discontinuities are indicated for the 500 and 625 to 750-m depth zones (Fig. 69). The species recruitment curve has the most pronounced increase at about 625 m (Fig. 68).

4.3.3 MAJOR INVERTEBRATE GROUP DESCRIPTIONS

The data obtained for each of the major invertebrate groups collected by trawling and fishes are not treated here, but are discussed in volume II.

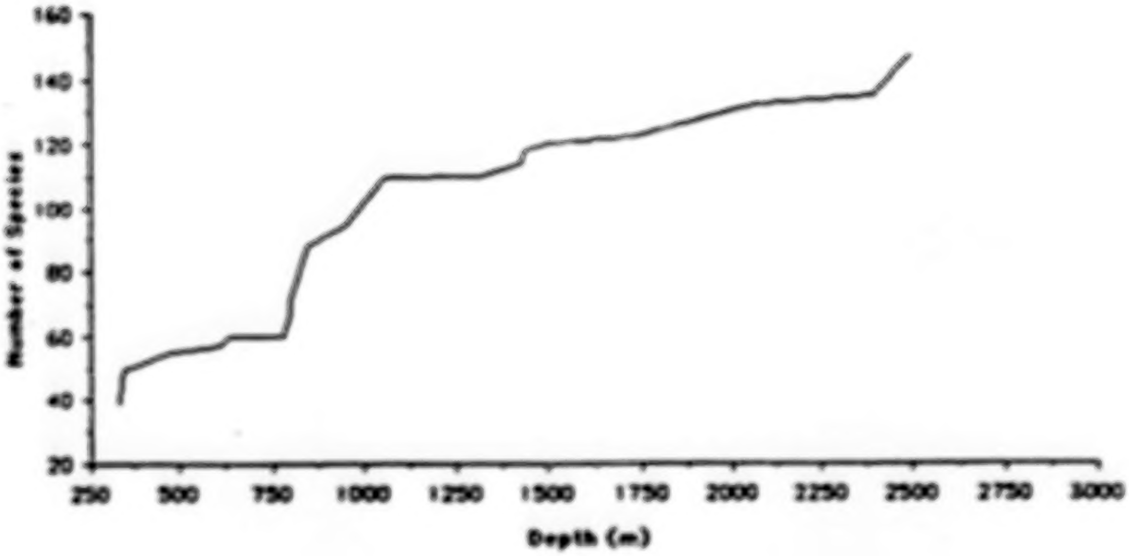


Figure 64. Species recruitment curve for invertebrate species trawled from the Central Transect. Compare with Chi-square values below.

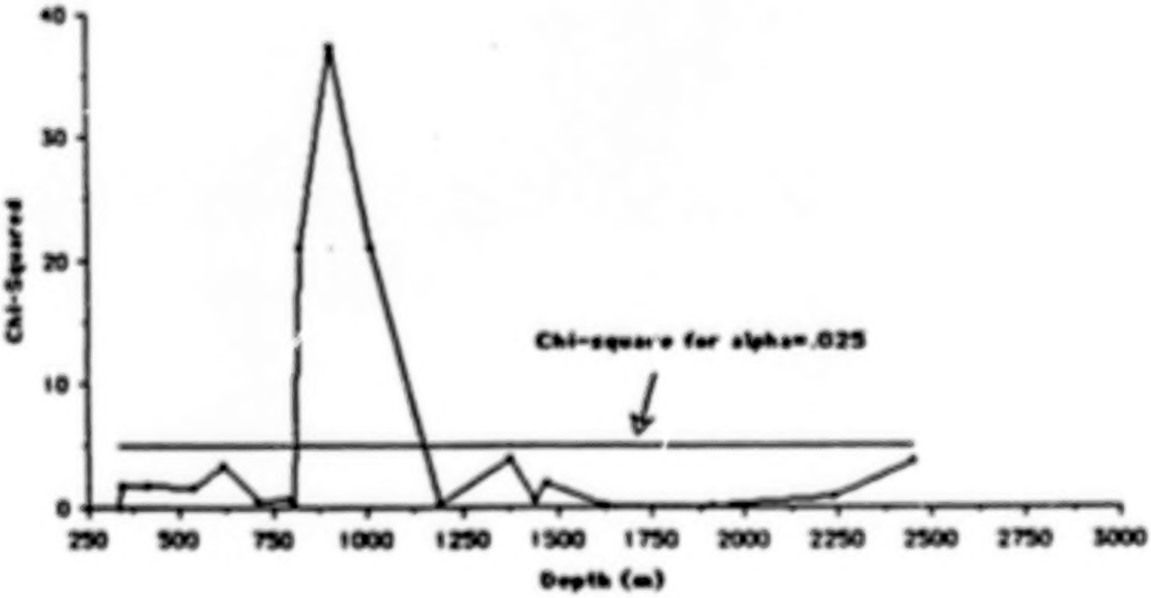


Figure 65. Chi-squared values for invertebrate species trawled from the Central Transect.

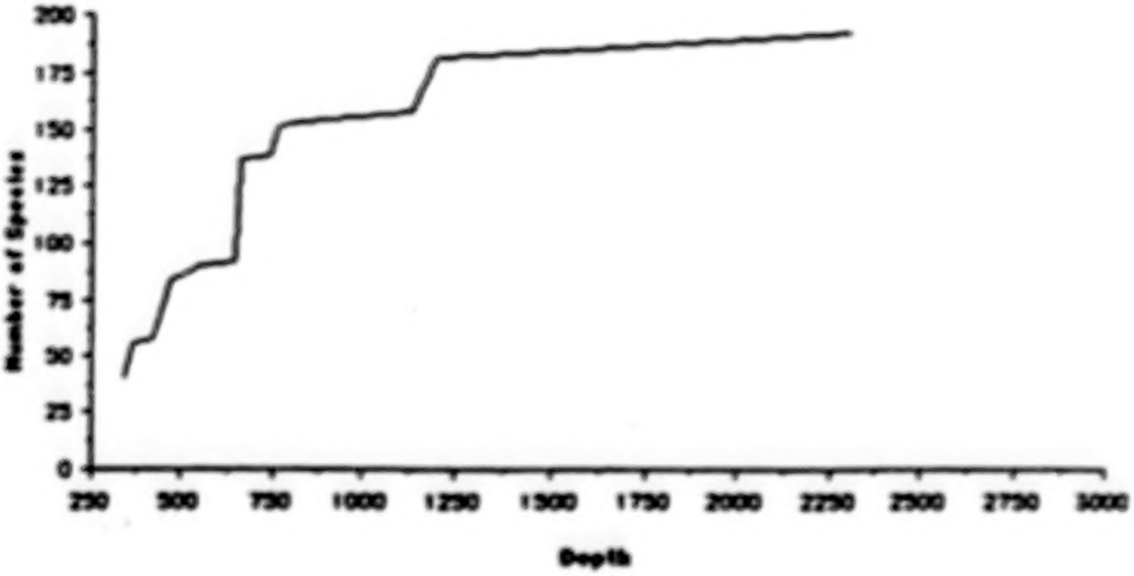


Figure 66. Species recruitment curve for all invertebrates trawled on the Western Transect.

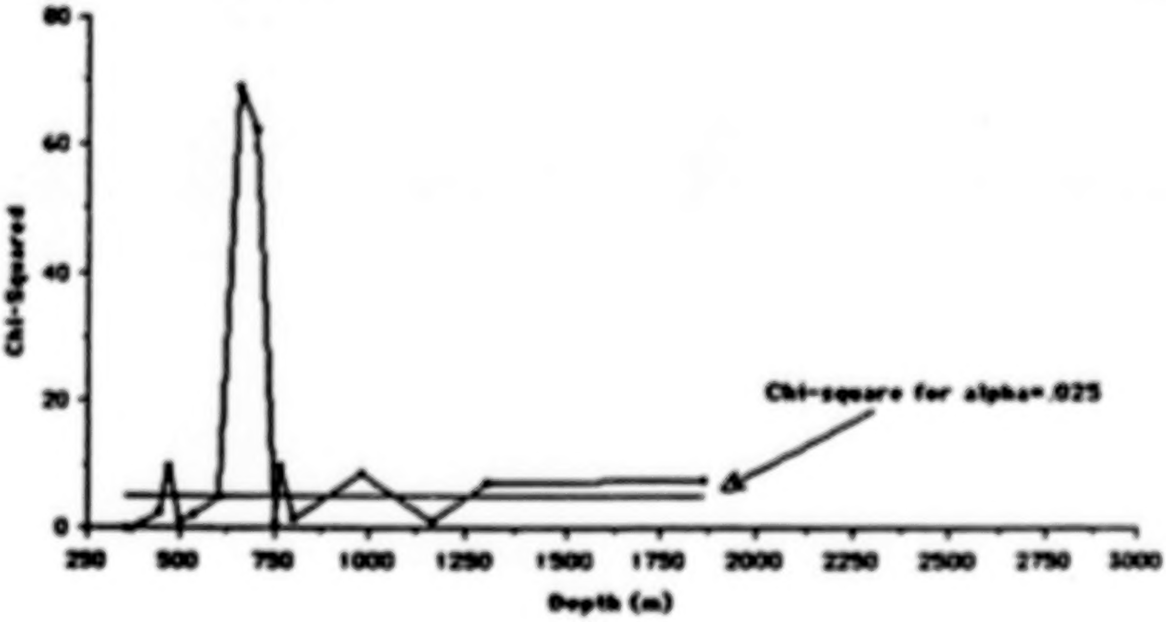


Figure 67. Chi-squared analysis of invertebrate species trawled on the Western Transect.

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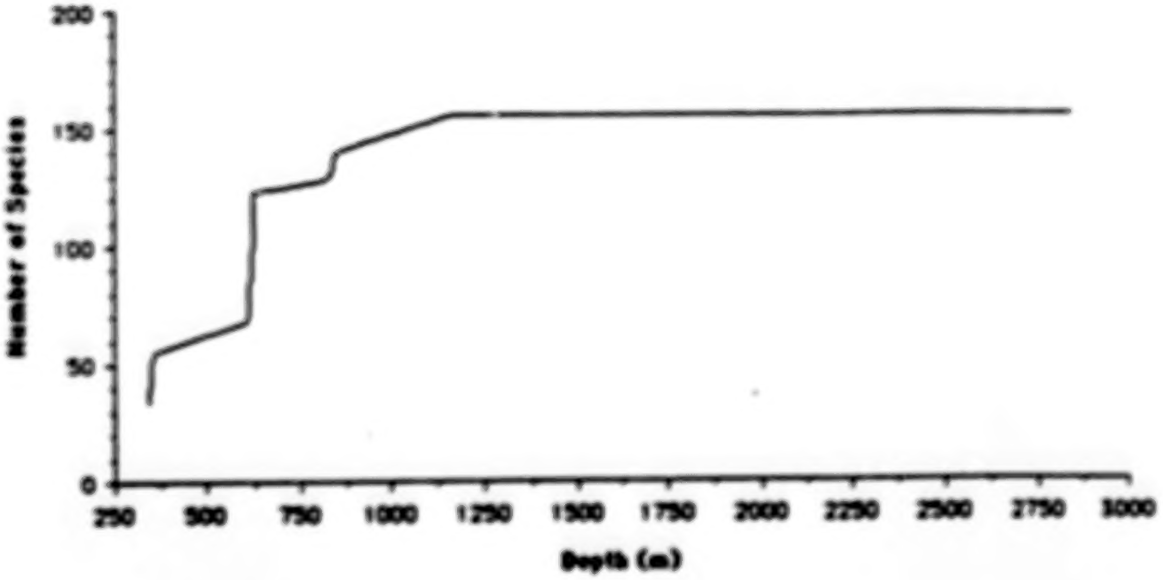

Figure 68. Species recruitment curve for all invertebrates trawled on the Eastern Transect.

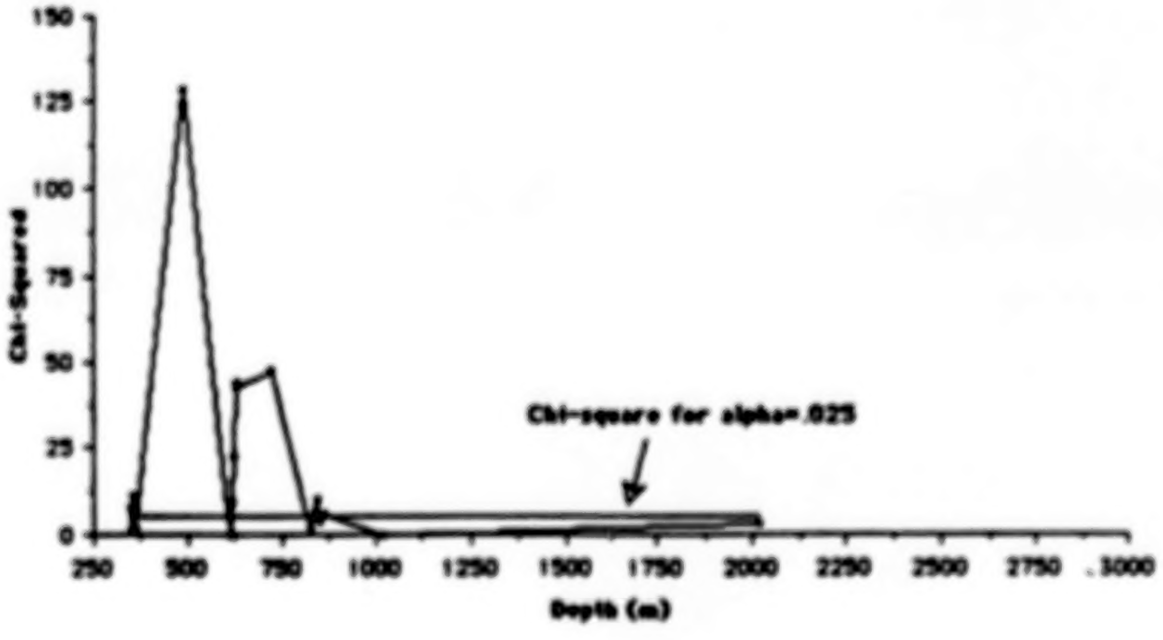

Figure 69. Chi-squared analysis of invertebrate species trawled on the Eastern Transect.

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5.0 BENTHIC PHOTOGRAPHY RESULTS

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5.0 BENTHIC PHOTOGRAPHY RESULTS

All 60 stations were sampled by benthic photography at depths ranging between 278 and 2893 m. Overall, a total of approximately 48,000 photographs were obtained. From these, a total of 9147 representing a bottom area of 24,590 m^2 were quantitatively analyzed for presence of biota. A total of 2321 of these frames were also further processed to quantitatively describe all sedimentary features left by the movements of animals. The knowledge of the scale of photographs allowed the interpretation of the area of the bottom shown in each photograph as a quadrat sample of the survey site and made possible the measurement of lengths or areas of various features and biota.

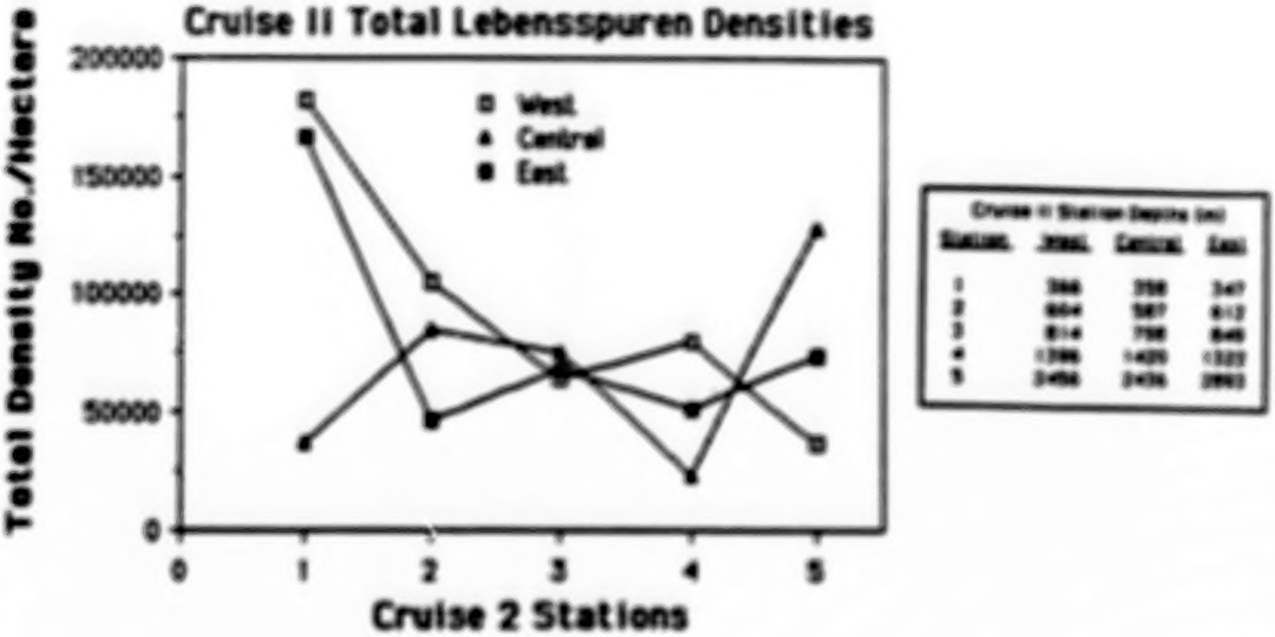
Lebensspuren (i.e., life traces), were the most abundant features of all photographs. A total of 56,272 individual lebensspuren features were documented. Figure 70 illustrates total lebensspuren density for Cruises II and III. Maximum lebensspuren density of 182,464 features/ha (18.2/m^2) was observed at Station W1 during Cruise II. Lebensspuren density ranged from this maximum to a minimum of 16,242/ha at Station C8 during Cruise III.

The most numerous single category of lebensspuren was "solitary depressions", representing burrows of various animals. During Cruise III, the density distribution of these features was similar to that of total lebensspuren with a maximum at Station C3 at 866 m (124,654/ha) dropping to a minimum at Station C8 at 1098 m (8817/ha).

In general, lebensspuren resulting from sedentary activities (i.e., dwelling or resting activities) greatly outnumbered those resulting from mobile or grazing activities.

Abundance of most megafauna taxa recorded with benthic photography was low. A total of 20,755 individual animals were recorded from the 55 stations analyzed quantitatively (Cruises II-V). Approximately 190 different taxa were represented. Some identifications were made at high taxonomic levels (e.g., families) but many groups wre identified to the species level.

Figure 71 illustrates total biota density for Cruises II-V. Overall megafauna density from all 55 stations combined was 8449 animals/ha. Mean density of biota was generally low at shallow stations and at stations in



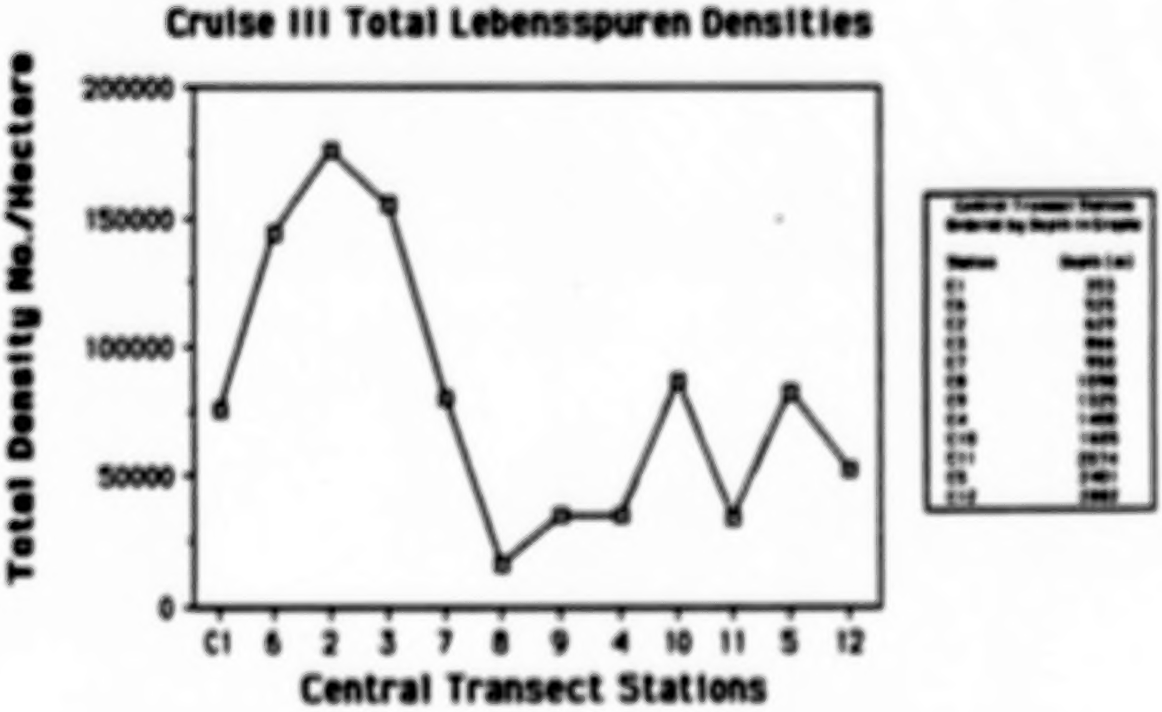


Figure 70. Total lebensspuren densities for Cruies II and III.

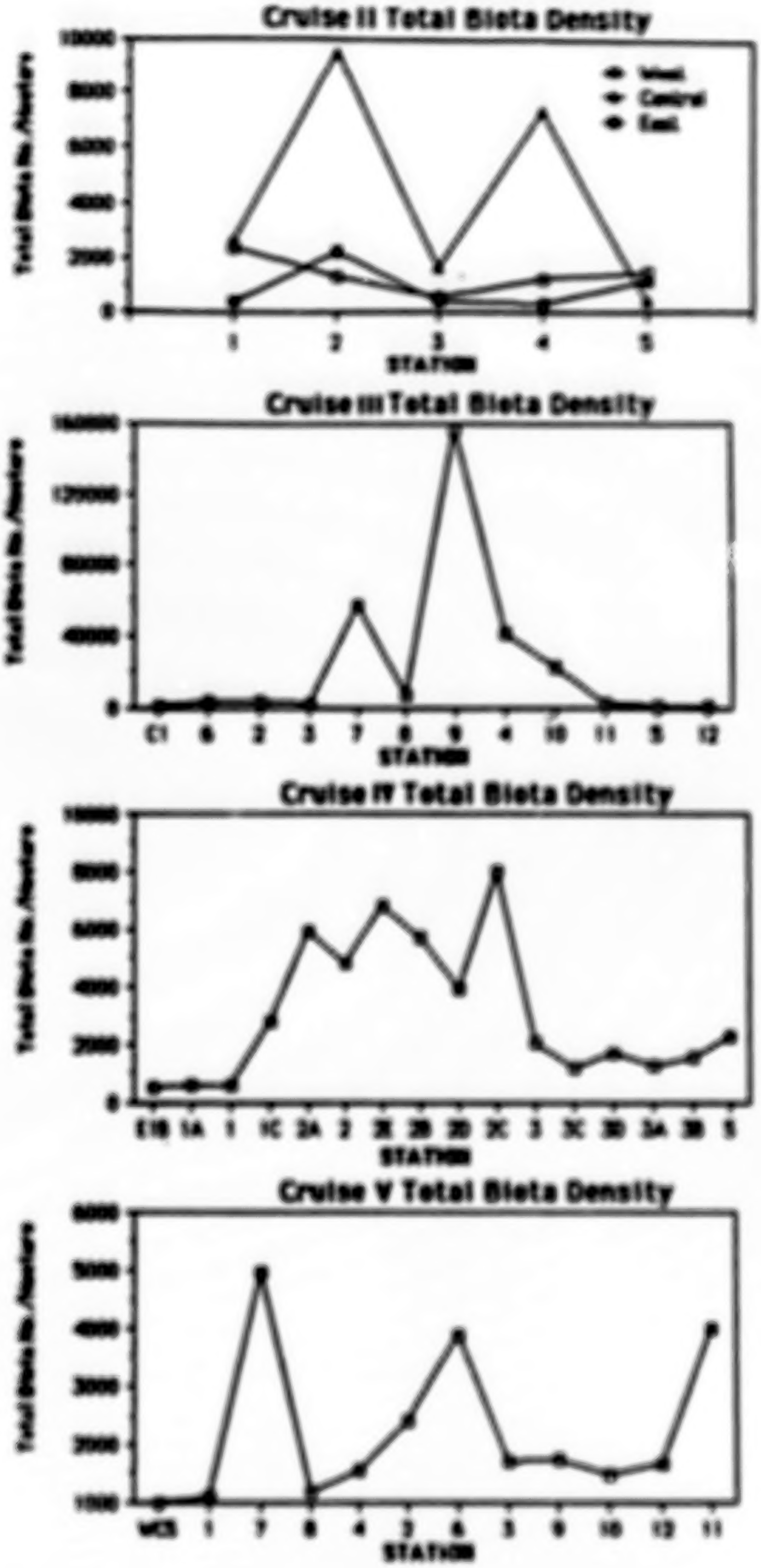


Figure 71. Total biota density from benthic photography by Station, Cruises II-V.

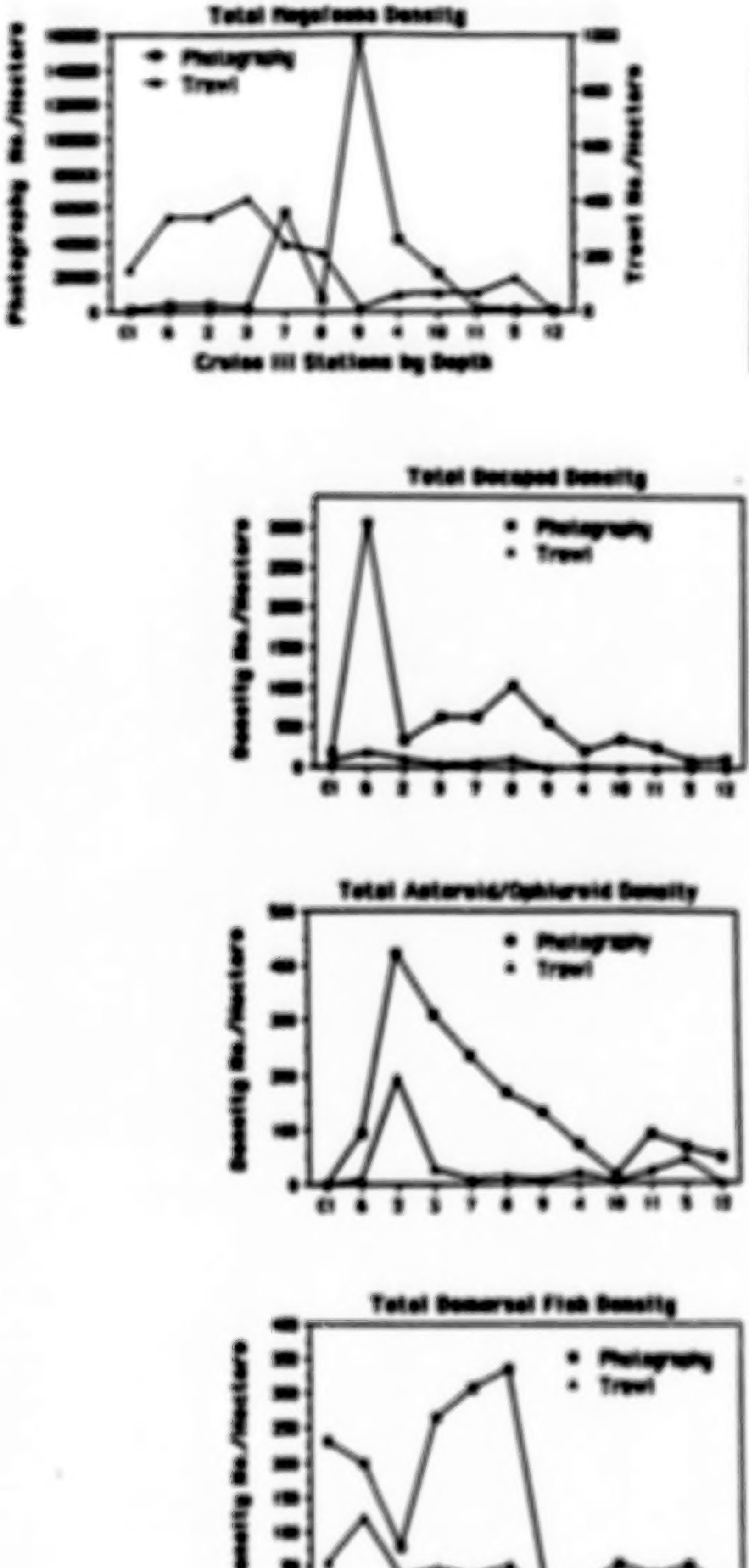
water deeper than 2000 m. The depth range interval between 1000-2000 m showed the highest mean density by more than a factor of five compared to the next highest depth interval of 500-1000 m.

Numbers of recognizable taxa in benthic photographs were very low in comparison to other sampling techniques. The maximum number of taxa was recorded at mid-depth stations in the depth increment of 500-1000 m. Station WC6 sampled during Cruise V at a depth of 552 m resulted in 34 taxa, the largest number from a single station.

By the use of custom digitizing procedures, length or area measurements of 16,377 animals were obtained. These data supplemented biota measurements obtained from trawl samples and in some cases were the only information documenting the presence of very significant megafauna taxa at many stations.

One of the most significant results from benthic photography sampling was its contrast with results from trawling. Megafauna densities obtained from benthic photography greatly exceeded those obtained from trawling with variations in some cases being more than four orders of magnitude. Figure 72 depicts density comparisons between benthic photography and trawl sampling from Cruise III. Total megafauna densities from benthic photography exceeded that of trawling at all Cruise III stations differing by no less than a factor of five (at Station C1; 769 animals/ha and 154/ha, respectively).

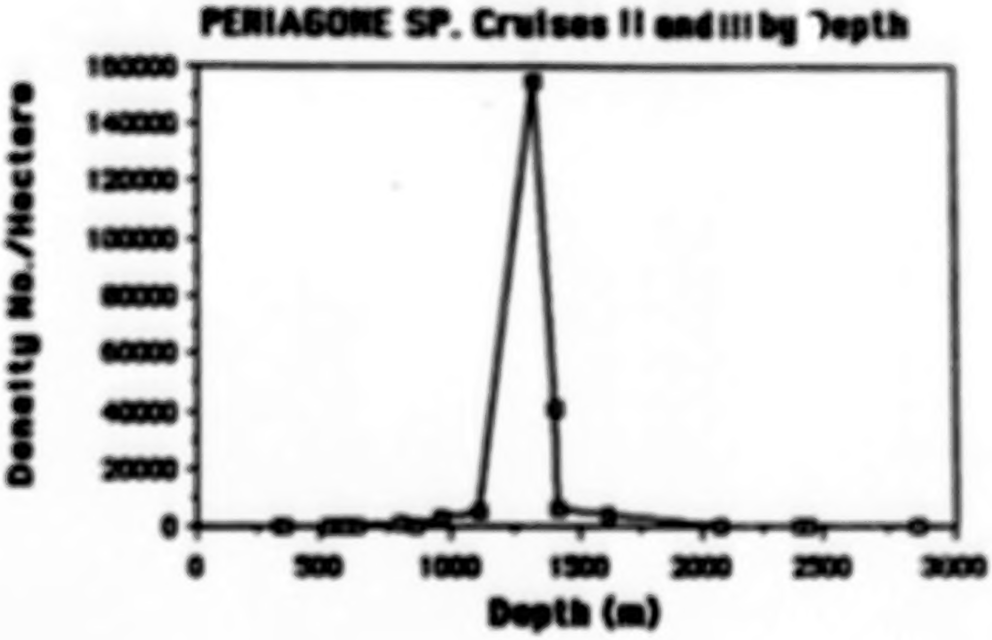
The dramatic differences between benthic photography and trawl densities in some cases was due to a small holothuroid, *Peniagone* sp. This organism was very abundant in Cruise III samples. It occurred at extremely high densities at several stations, but was never taken by trawling. *Peniagone* sp. was the most abundant organism at all 60 stations sampled by benthic photography, having a peak density of 154,669 individuals/ha at Station C9 on Cruise III. Figure 73 illustrates the density distribution of this taxa and length distribution of the 10,581 measurements that were obtained. The biomass represented by this single organism would be substantial and a very significant proportion of the total biomass in the areas where it occurred.



Central Transect Stations
Ordered by Depth in Graphs

Station	Depth (m)
C1	353
C6	525
C2	625
C3	866
C7	950
C8	1098
C9	1325
C4	1428
C10	1605
C11	2074
C5	2481
C12	2882

Figure 72. Megafauna density comparisons of trawl and benthic photography, Cruise III.



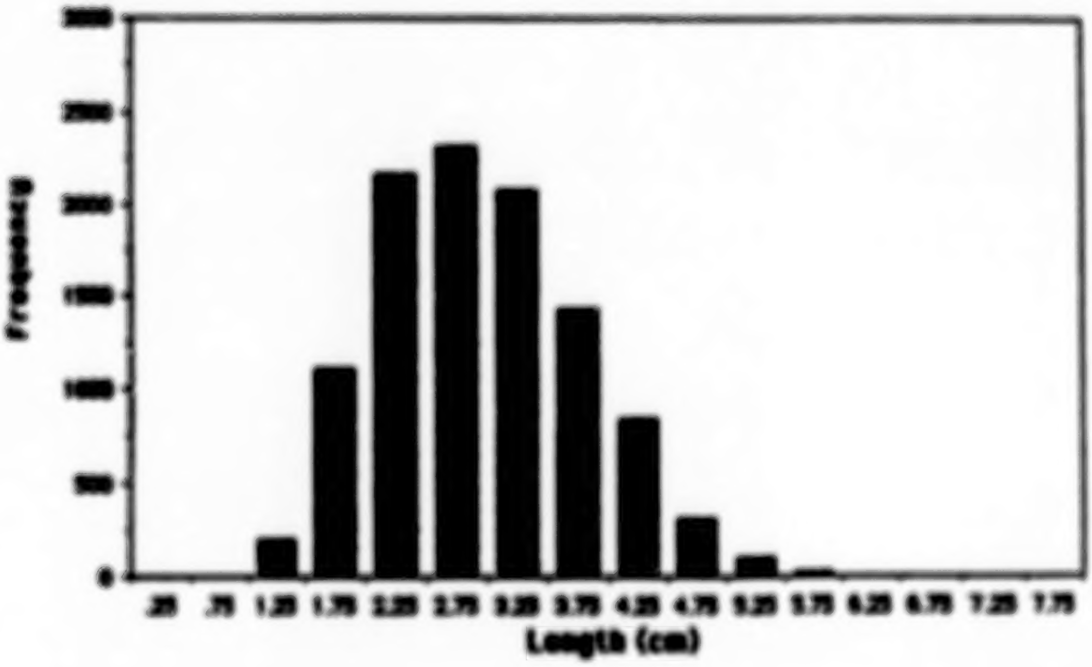


Figure 73. Distribution by depth and length frequency distribution of _Peniagone_ sp., Cruises II and III.

6.0 REFERENCES

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Backus, R.H., G.W. Mead, R.L. Haedrich and A.W. Ebeling. 1965. The mesopelagic fishes collected during Cruise 17 of the R/V CHAIN, with a method for analyzing faunal transects.

Bowman, K.O., K. Hutcheson, E.P. Odum and L.R. Shenton. 1971. Comments on the distribution of indices of diversity. P. 315-359. In: G.P. Patil, E.C. Pielou and W.E. Waters (Eds.), Statistical Ecology, Vol. 3. Pennsylvania State University Press, University Park.

Calder, J.A. and P.L. Parker. 1968. Stable carbon isotope ratios as indices of petrochemical pollution in aquatic systems. Environ. Sci. Technol. 2:535-539.

Carney, R.S., R.L. Haedrich and G.T. Rowe. 1983. Zonation of fauna in the deep sea. P. 371-398. In: G.T. Rowe (Ed.), Deep-Sea Biology. John Wiley and Sons, New York. 560 pp.

Cochran, W.G. 1977. Sampling techniques. John Wiley and Sons, New York. 428 p.

Degens, E.T., M. Behrendt, B.G. Gotthardt and E. Reppman. 1968. Metabolic fractionation of carbon isotopes in marine plankton-II: Data on samples collected off the coasts of Peru and Equador. Deep Sea Res. 15:11.

DeNiro, M.J. and S. Epstein. 1978. Influence of diet on the distribution of carbon isotopes in animals. Geochim. Cosmochim. Acta 42:495-506.

Fauble, A. 1982. Determination of individual meiofauna dry weight values in relation to definite size classes. Cahierss de Biologie Marine, Tome XXIII:339-345.

Folk, R.L. 1974. Petrology of sedimentary rocks. Hemphill Publishing Co., Austin, Texas. 182 pp.

Fry, B. 1981. Natural stable isotope tag traces Texas shrimp migration. Fishery Bull. 79:337-345.

Fry, B. and P.L. Parker. 1979. Annual diet in Texas seagrass systems: ^{13}C evidence for the importance of benthic plants. Estuarine Mar. Sci. 8:499-509.

Gage, J.D. 1986. The benthic fauna of the Rockall Trough: regional distribution and bathymetric zonation. Proc. Royal Soc. of Edinburgh. 88B:159-174.

Gearing, J.N., P.J. Gearing, D.T. Rudnick, A.G. Requeijo and M.J. Hutchins. 1984. Isotopic variability of organic carbon in a phytoplankton-based temperate estuary. Geochim. Cosmochim. Acta. 38:1089-1098.

Grassle, J.F. and W. Smith. 1976. A similarity measure sensitive to the contribution of rare species and its use in investigation of variation in marine benthic communities, Oecologia. 25:13-22.

Grassle, J.F., H.L. Sanders, R.R. Hessler, G.T. Rowe and T. McLellan. 1975. Pattern and zonation: a study of the bathyal megafauna using the research submersible Alvin. Deep-Sea Research. 22:457-481.

Haedrich, R.L., G.T. Rowe and P.T. Rollini. 1975. Zonation and faunal composition of epibenthic populations on the continental slope south of New England. J. Mar. Res. 33:191-212.

Haedrich, R.L., G.T. Rowe and P.T. Rollini. 1980. The megabenthic fauna in the deep sea south of New England, USA. Mar. Biol. 57:165-179.

Haines, E.B. 1976. Relation between the stable carbon isotope composition of fiddler crabs, plants, and soils, in a salt marsh. Limnol. Oceanogr. 4:880-883.

Haines, E.B. and C.L. Montague. 1979. Food sources of estuarine invertebrates analyzed using $^{13}C/^{12}C$ ratios. Ecology. 60:48-56.

Nowlin, W.D., Jr. and H.J. McLellan. 1967. A characterization of the Gulf of Mexico waters in winter. J. Mar. Res. 28(1):29-59.

Parker, P.L. 1964. The biogeochemistry of the stable isotopes of carbon in a marine bay. Geochim. Cosmochim. Acta. 18:1155-1164.

Pequegnat, W.E. 1983. The ecological communities of the continental slope and adjacent regimes of the northern Gulf of Mexico, prepared by TerEco Corp. for Minerals Management Service, U.S. Dept. of Interior Contract AA851-CT1-12. 398 pp. + appendices.

Rau, G.H. 1981. Hydrothermal vent clam and tube worm $^{13}C/^{12}C$: further evidence of non-photosynthetic food sources. Science 213:338-340.

Rau, G.H. and J.I. Hedges. 1979. Carbon-13 depletion in a hydrothermal vent mussel: Suggestions of a chemosynthetic food source. Science. 203:648-649.

Rowe, G.T., P.T. Polloni and S.G. Horner. 1974. Benthic biomass estimates from the northwestern Atlantic Ocean and the northern Gulf of Mexico. Deep-Sea Research. 21:641-650.

Sackett, W.M. 1964. The depositional history and isotopic carbon composition of marine sediments. Marine Geol. 2:173-185.

Thiel, H. 1983. Meiobenthos and nanobenthos of the deep sea. In: G.T. Rowe (Ed.), Deep-Sea Biology. Chap. 5. John Wiley and Sons, New York.

Williams, P.M., K.L. Smith, E.M. Druffel and T.W. Linick. 1981. Dietary carbon sources of mussels and tubeworms from Galapagos hydrothermal vents determined from tissue ^{14}C activity. Nature. 292:448-452.

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